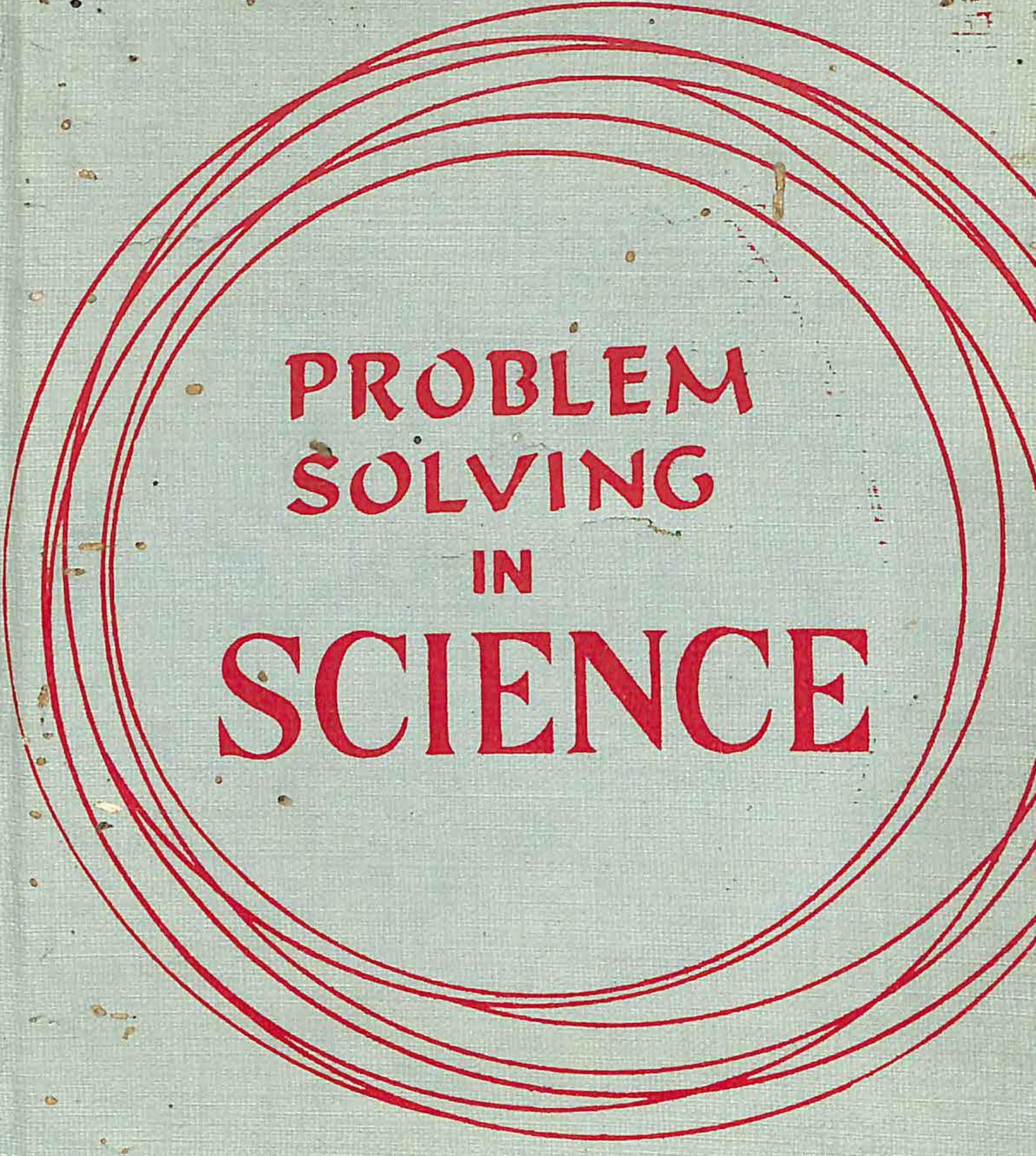


PROBLEM SOLVING IN SCIENCE

NARENDERA VAIDYA

~~2441~~
~~6515~~
Govt. of West Bengal * STATE
~~3441~~
3954
27.4.87

PROBLEM SOLVING
IN
SCIENCE

STATE INSTITUTE OF EDUCATION
Govt. of West Bengal.

Ahmeditations

Fascinating things—figures !—I mean, the sort you learn at school—you know, arithmetic and all that. You come across an item like "Electricity produced by public utility power stations in India amounted to 1,038·2 million KWH in August, says an official Press release."—Makes you think, doesnt's it ?

It made me think !—I know what KWH stands for—Kilo Watt Hours—see ! 1,038·2 million is more than I can absorb. Even at school my teachers used to say I would be the death of them when they were trying to teach me how to count up to 100.

And while I am still fascinated with any figure over one million, it would be so much more fascinating if official Press releases let themselves go a bit as they do in the private sector.

You read an announcement that a particular airline has just completed one million flying miles. But then they go on to tell you that is equal to "so-many-times-round-the-world." This brings it down to your level of intelligence. They go a step further and tell you it is equal to two trips to Venus and back—which brings it down to mine—space—cosmic level.

So why can't we be told how many table fans, refrigerators, air-conditioners and hair-dryers would work for how long on 1,038·2 million KWH—Not that it would mean anything more to me, but it would be so much more fascinating. Don't you think ?

From the Hindustan Times dated 9th December, 1958.

1c

PROBLEM SOLVING
IN
SCIENCE

STATE INSTITUTE OF EDUCATION
Govt. of West Bengal.
~~3441~~
15965

By

NARENDERA VAIDYA

M.Sc. Hons. School & B.Sc. Hons. School
Physics Honours School, Punjab University
M.Ed. (C.I.E. Delhi) & M.A. (Institute of Education, London).
Reader in Education
Regional College of Education (N.C.E.R.T.)
Ajmer (Rajasthan).

S.C.E.R.T., West Bengal
Library
Calcutta
25/3, B. C. Ro

1968

S. CHAND & CO.

DELHI — NEW DELHI — JULLUNDUR
LUCKNOW—BOMBAY—CALCUTTA—MADRAS

S. CHAND & CO.

Ram Nagar — NEW DELHI
Fountain — DELHI
Mai Hiran Gate — JULLUNDUR
Aminabad Park — LUCKNOW
167, Lamington Road — BOMBAY
32, Ganesh Chandra Ave.— CALCUTTA
35, Mount Moad — MADRAS

S.C.E.R.T., West Bengal
Date 27-4-87
Acc. No. 3954

372.3
VAI

Price : *Rs.* **12·50**

Published by S. Chand & Co., Ram Nagar, New Delhi-1
and printed at Rajendra Printers, Ram Nagar, New Delhi-1.

Foreword

The world we live in is a marvel of man's mastery over his environment. Through the explosive development of the natural sciences we now predict, control and understand phenomena to an extent never fully envisioned throughout the millions of years of human development prior to the current century. The scientific revolution has maximized opportunities for human happiness, and through its technical arms, is providing material wealth and long and healthy lives. New knowledge and the process by which it is obtained, promise a spiritual fulfilment unavailable from the dry bones of fatalism and mysticism.

Fundamental to the conquest of nature by the scientist has been his method of approach to the unknown. Facts and understandings bring the scientist to the frontier, but it is scientific methodology that extends the frontier of knowledge.

For the student of science—for the citizen who must live in harmony with the times and participate constructively in a scientifically impacted society—information alone does not create literacy. The individual must learn through personalized experience the manner in which new knowledge is won from its natural ore.

Narendera Vaidya is a pioneer in science education. From his experience as an effective teacher of physics and curriculum and methods in science courses, his experimental studies on problem solving in English grammar schools, and his commitment to scour the research literature for new ideas about problem solving in science, he has assembled and composed this treatise.

Problem Solving in Sicence provides the Indian science teacher with a new rationale for realizing process objectives in teaching. The reader is confronted with a plethora of definition and is dragged through the diffuse labyrinth of the theoretical foundations of science teaching. But a comprehensive review of the research literature of educational pyschology generates hope that a framework in problem solving theory is emerging. The author's own experimental work reinforces the conviction that science teaching based upon problem solving, and not merely the transmission of information, can significantly raise the level of scientific literacy for the citizen and accelerate the rate of production of practising scientists.

The day when school science is taught and learned in the manner in which science is created by man has been brought nearer by **Problem Solving in Science by Narendera Vaidya.**

IRWIN L. SLESNICK
Professor of Biology,
Western Washington State College &
Science Education Adviser
United States Agency for International
Development, New Delhi

August 1967

Preface

Possibly excluding a few science teachers and schools, the teaching of science in our country is dull, dead, mechanical, absolutely boring and devoid of any constructive imagination. The reasons for the same are not at all difficult to find—the most important and blind being the inelastic examination approach to teaching science by the science teachers and learning by the students. (This argument is applicable to General Science as well). This pays both of them dividends—less effort on the teacher's part for he uses mechanical approach (even Skinner, the advocate of teaching machines will not be too much pleased with them) and more marks for the student in the examination for his highly mechanical, set and routinized habit of thinking and doing appear to pay him off handsomely. This, for the student, is also the path of least resistance. It is no wonder then that most of our science students and possibly teachers cannot think effectively and independently for themselves. The last part of the preceding statement is highly disturbing for this nascent nation, because an independent and developing nation like ours cannot survive long on borrowed consultants, borrowed money, borrowed technical skills and, much worse in borrowed thinking and carbon copy type of working, habits (imitation) especially when our country is heavily committed to science, technology, and industrialization. I hardly need stress the fact that for achieving this industrial revolution, science teaching in our country has to be radically different from the one that prevails to-day in the light of the problems (philosophical, p sychological, sociological, technical, scientific etc.) with which we are faced to-day, particularly speaking, as a result of long colonial rule. These are too difficult problems for the author to answer ; he, therefore, attempts little in this book.

The object of all education and especially of science and mathematics, in the words of Sir John Newson, is "to produce questioning spirit, to make people dissatisfied with cant and hypocrisy, to make them want to find out and test things for themselves and want to go on growing". This self-direction is conspicuous by its absence in our approach to science teaching. It is here that our science teachers have to pool their talents and resources in science education which really result in the growth of scientific knowledge and temper among the vast body of children still at school. We should remember that thousands of science teachers working in our schools today are in fact shaping the future scientific and technological India. Unlike in the U.S.A., the U.K. or the European countries including the U.S.S.R., the danger to our science education is much more in this country in the absence of any continuing debate or controversy on scientific education and scientific policy with special reference to school science.

Discovery approach to science teaching, mastery of research operations, teaching for problem solving, scientific method and the improvement of thinking and finding out things on our own etc., are the ferments which need to be produced, developed, cultured and grown in our science education towards the closing half of the twentieth century and even beyond it—because this is the future demand of the times arising out of the second industrial revolution. This book is, therefore, written for those who believe firmly in these ferments. Naturally, the book contains chapters on the outcomes of Science Education, the theoretical nature of thinking and problem solving in science, a survey of Human Problem Solving which incorporates and elucidates the basic ideas of the gestalt pyschologists (Wertheimer and Duncker etc.) ; Piaget and Inhelder ; Vygotsky and others ; uptodate researches on school science, teaching abroad, an experimental study of problem solving conducted by the author and the practical implications of the point of view developed in this book for first class science teaching. In passing, mention is made of evaluation and the maintenance of reflective atmosphere in our ordinary classrooms. A full bibliography on problem solving is further appended at the end of the book.

Chronologically speaking, the material for the preparation of this book has been collected over a number of seven years at the Central Institute of Education library, Delhi ; Teachers Training College library, Udaipur ; Institute of Education library, London ; The Senate House, London ; Department of Education library, Birmingham ; Institute of Education library, Birmingham ; Department of Education library at Kurukshetra University, Kurukshetra and the Regional College of Education library at Ajmer. For the personalities, I would very specially like to thank Dr. (Mrs.) Krishna Swami, ex-Director of the Central Bureau of Text book Research, Delhi, Dr. (Mrs.) Koshy, ex-Vice Principal, C.I.E., Delhi, the late Principal P.L. Shrimali, Teachers College, Udaipur and Mrs. D.M. Penfold, senior lecturer in statistics and my tutor at the Institute of Education, London. They are the personalities with whom I had serious discussions and in the process have disagreed strongly on certain points right up to my breaking point. At the same time, I owe much to them for raising controversies which have now ended for me in an abiding life-long interest in the whole area of thinking. Personally, I consider this a big gain. It has been a great pleasure and I have enjoyed myself working under each of them.

Lastly, we science teachers in our exciting times should also now build an Indian Tradition of Science Teaching. For this, no advice is given and no suggestions are made because here we must first do our own home task, rely more on our own thinking, reach our own decisions however wrong they might be, rather than depend upon imported brand (stuff) or foreign solutions. Thus we should not remain satisfied with one solution alone. More alternative solutions should be sought, tentative stabs examined and then investigated upon to yield fruitful solution. We will then be rectifying our own thinking gradually through self-exploration, observation, experimentation, etc. We will thus grow in self-confidence and persistence. And this is Problem Solving. No one then need to order us about our job. This however is possible only if each one of us works beyond a certain minimum standard agreed nationally.

March, 1968,

NARENDERA VAIDYA

Contents

Pages
Ahmeditations ... (ii)
Foreword ... (v)
Preface ... (vii)
I. Background ... 1
Teaching Abroad ... 1
Science Teaching in England ... 8
Science Teaching in India ... 12
II. Outcomes of Science Education ... 36
Impact of science and technology, self acceleration of science, what is science ? Aims of science teaching, outcomes of science education : functional understandings, scientific skills, scientific attitudes, scientific interests and scientific appreciations
III. Thinking and Problem Solving ... 49
Thinking, productive thinking, problem solving, logical steps in problem solving, illustration of problem solving, classification of problems, selection of problems, experimental problems, symbolic problems, numerical problems, mixed problems and concluding statement
IV. Survey of Human Problem Solving ... 66
Problems to be investigated ... 67

SECTION A

Maltzman's theory, programmed learning,... 69
Gestalt school, phenomenological theory, Geneva School, acceleration of mental development : Vygotsky's view, Dienes Z.P's view, Factor Analysis as a method of investigation and information processing

SECTION B

Problem Solving ... 95

Studies in concept formation, studies in problem solving and teaching of science, objective tests and concluding statement

V. **An Experimental Study** ... 116

Aims of this study, method of procedure, sample and subjects, tests used, problems used, results of this study, factor analysis of the problems and the tests used, interpretation of factors, analysis of problem solving processes, Guttman analysis, role of hints and cues, some statistical relationships, role of difficult words, differences between successful and unsuccessful problem solvers, summary and suggestions for further research

VI. **Implications for Science Teaching** ... 151

Immediate reactions to the problem, distinction between relevant and irrelevant variables, role of hints and cues, use of programmed techniques, generalization of algebraic symbols and mathematical thinking, interests in problem solving, a progressive science lesson for problem solving, analysis of problem solving processes, evaluation and attainment of economy

VII. **Further Problems Ahead** ... 165

References consulted ... 171

CHAPTER 1

Background

TEACHING ABROAD

Perhaps it is the curiosity of man or some compulsive tendency in him that drives a man forward either in research or in leaving behind his permanent abode, relatives, friends, surroundings, and even wife and children. He does not then pre-arrange things but on the other hand finds a chance opportunity and utilizes it fully. Dissatisfaction and frustration with self and surroundings, with hope thrown in, oscillate him and his life. This has its own advantages and disadvantages. Their absence implies life of calmness, stability, moving with a uniform speed, no make-and-break in the existing scheme of things and finally no extra incentive in life. Their presence in one's life otherwise implies developing acquaintance and friendship with nervousness, anxiety, fear, agony, confusion, unemployment and possibly jumping from hope to hope and even beyond. To this class of people, going abroad is an educative experience. He then encounters new experiences, meets new people having different backgrounds, ideas, emotions, character etc. and consequently develops new insights which he would not have otherwise developed. For him, then, obtaining a degree is of secondary importance. It is only then that the craving for reaching the top starts and gains momentum later on. On returning home, he finds himself wholly transformed in his thinking, feeling, doing and approach to the problems—academic, professional and personal. He develops self-confidence and an urge to attempt and accomplish bigger tasks at home. If this thing happens, the study visit abroad has paid its dividends both to the nation and the individual. Otherwise, his visit remains and will remain a paper experience of very little use to the nation, because in that case he will be reaping the fruits of his qualifications and experience for many many years to come due to the above mentioned built-in advantage, not shared by his counterparts who have not been abroad; for a good job to-day depends more on a foreign degree than on development of trained intelligence the Swedeshi way.

This author stayed in England over three years (1961 - 64) and in this duration, he taught physics and mathematics in Grammar and Technical High schools. He further observed intensively the working of a comprehensive and a Secondary Modern School meant mostly for the education of the average, non-academic and backward pupils. During his stay, the author was more impressed by the following than by any educational principles which we read in our education text-books. These were : use of sheer commonsense and intelligence, developing highly intelligent and imaginative approaches in teaching, making the best use not only of limited resources but of the worst possible resources, development of an education programme according to the age, ability and aptitude of each, demonstration of self-confidence and persistence in critical situations, development and growth of self-thinking, self-exploration and self-instruction on one's own—and thereby to contribute one's mite in those problem situations which stare him and his nation in the face—and a very high degree of self-involvement in one's own work. A science sixth former of good brains does not wish to choose his future career in technology. On the other hand, he is very eager and keen to pursue a pure research career. This is the reason that England even to-day is one of the leading countries of the world so far as pure research is concerned. The author has written this in the hope that a few of the above mentioned features might interest us in this country. No suggestions are made because here we must do first our own hometask, rely more on our own thinking and imagination rather than depend upon imported brand, learn our own lessons in our own situations and lastly help in the building up of an Indian tradition of Science teaching. This much is enough for us.

It is said that the British Educational System is the best in the world provided one can 'survive' it. Ours also is at the top in the world if it is judged by the sheer output of graduates who can't think for themselves because they are academically under-fed and statutorily over-examined right from the 10th class onwards. In the end, they neither turn out as 'academic' fishes nor 'vocational fowls' as the very course of higher instruction in this country is based upon fixed questions and fixed answers, mechanical teaching devoid of imagination, out-moded content, absence of first hand experience and lastly, the very element and ferment of self-education that educates the scholar himself all along his way is utterly lacking in our schemes of higher education.

It is very difficult to describe their educational system because it is highly decentralized. Every teacher works in his own unique way because they believe rightly that the man on the job knows more than the Headmaster in his office. The most surprising thing to note is that this mutual trust simply works both ways. High standards of attainment and conduct among those who are capable, firm faith in first hand experience and the use of sheer commonsense rather than too much reliance on philosophy and psychology, personal example rather than speech coupled with the virtues of a good Christian, strength of conviction rather than the fear of authority, learning by trial and error like Thorndike's rats, plugging of loopholes wherever they occur, personal freedom, respect for the individual and his time, etc., are some of the features of the English Educational System (which even a blind man also sees like the dropping of bricks) that are being intensively developed in varying degrees by a band of devoted school teachers. Their only qualifications are possession of reasonable amount of knowledge, favourable attitude towards work and the development of individual interests which they in turn cultivate among their interested students. An outsider, whatever may be his leanings, will find nothing sensible in the English System of Education. I will be surprised if an English Headmaster even today is able to tell you something worthwhile and significant about the aims and objectives of his school. If he becomes informal over a cup of tea, he will talk more of his own foolhardiness than of his school ideals, achievements and methods. This is the crust of their educational system. If you break this crust, you will find that there is a lot of thought, action, research and progressive ideas at work beneath it which make their educational system quite unique in character. Being one of them for a couple of years, I have been personally impressed by its following outstanding features.

Emphasis on Quality

Coal, fish and brains are their sole resources. They, therefore, cannot risk becoming a nation of mediocres. Their whole educational system is geared to the 'highest education of the higher intellectual' at the state cost. At 11 plus, about 75% of the pupils are diverted to the non-academic type of education. It is interesting to note that their education is mostly of the Basic Education type (its few dogmas excluded) in spirit which our academicians not only failed to understand and appreciate but also implemented it disappointingly and sorrowfully overnight without adequate experimentation. For the rest, the highly specialized education begins at 11+. At 18+, one gets a highly specialized sixth former who can, largely speaking, think for himself unaided. It may be added here that even among the Grammar Schools, the standards of attainment differ very widely. A sixth former chooses only those subjects in which he or she is genuinely interested. The examination requirements are not only stiff but also highly demanding and exacting in nature. Roughly, over 5-7 p.c. of such pupils go to a University. Each one of them chooses the university of his or her choice. Depending upon the financial position of the parent, the county practically pays for all expenditure which sometimes even covers travel home during vacations. After the first year at the University, failure at the university is perhaps the minimum in the whole world. So places and resources are not foolishly wasted.

Methods of Teaching and Education

This is based upon empirical observation. They do not talk of any educational principles as such as if they have none. Every teacher is free to experiment and develop his own course of teaching. In fact most of them develop their own schemes of work after years of experimentation. Somebody somewhere is digging his own hole. I never found anybody bothering about child psychology. They, in fact, appear to ridicule the experts. Science teachers develop their own apparatuses and teaching aids. Their contribution in this respect is monumental. Practically, the whole of Science teaching is demonstrated before the very eyes of the pupils. Being intelligent observers of children and the type of environment they come from, teachers in small groups and on voluntary basis, develop special courses for the education both of academic and non-academic pupils. The very characteristic of their work is variety (and not publicity!) rather than uniformity which takes into account the local variations. Nobody talks in the air. If he does, he is ridiculed for he has not experimented his ideas even on his own children. During my stay there, I did not discover any methodology of teaching except the use of instinct, commonsense, personal observation and experimentation and the very pursuit of ideas that appeal to them and possibly also show some promise. For example, ideas of Piaget, a Swiss psychologist, are increasingly becoming popular with the primary school teachers.

Examinations

Emphasis is on education rather than on examination. Consequently, examination is not compulsory for all, only those take examinations who think they can. At the G.C.E. (O Level), all papers are first marked and the pass fail point is decided on the basis of a curious average which varies between 47% to 52% in each paper. One can pass G.C.E. with one subject, two subjects and even 10 to 12 subjects depending upon one's capacity. Papers are first marked numerically and the result is then announced in grades. There is, therefore, no overall first class, second class or third class. Everybody is given a grade in the subject examined. Grade one is the highest.

For those who are not capable of taking G.C.E., they are now instituting a new examination called C.S.E. which is practically teacher-dominated. Certificate of Secondary Education is one of the most imaginative examinations conducted anywhere possibly including U.S.S.R. This is so because it is developing out of the practical difficulties facing the kids and their teachers. It may be added here that it is not the short version of the G.C.E. examination. It even tends to test thinking not tapped by the existing G.C.E. question papers.

Sixth Form

These are generally the last two years at school. The element of self-education is enforced at this stage. They have a few regular periods. Rest of the school time is planned according to the needs and aptitudes of each. They are largely made to work on their own. It will not be out of place to mention that special situations are designed by the school singly or on group basis where most of the sixth formers may develop responsibility, initiative, resourcefulness, ingenuity, attention to details, consideration and concern for others and even the development of personal conscience. A sixth former will never leave you in doubt what he or she actually feels when he or she is asked to comment freely upon any issue. Here again, they specialize in one, two or three subjects of their choice. They can also add a few more ordinary level subjects if they want to. Excursions, visits to definite places of educational interest and group discussion on current problems receive good attention. Along with specialization, general education is also emphasized.

No decision is made on a single question paper. There is no internal assessment because it is not only not likely to be misused but also to be misunderstood. In our country, a single question paper decides so many things : scholarship cases, first class, second class and third class and even failures. A student is declared failed if he fails say in mathematics. That is not so in England because only a devil there can set such a type of examination for all the above-mentioned categories of pupils. My impression is that a sixth former is 2-3 years ahead in trained intelligence with respect to our first class students of the same age.

School Inspection

The inspection of schools is both human and humane. It is generally advisory and optional. No one is afraid of the inspector—neither students nor teachers. In my class, the H.M. inspector started questioning one of the back benchers on her various steps reached in the solution of a physics problem. When exhausted, she (age 14 plus) blurted out "Thanks for your questioning. I wish you could please mind your own business; you know, Mr. Vaidya is my teacher". The inspector gave an apologetic look when he related this incident to me. At the end, the inspector thanked me for allowing him to inspect my class. Other Indian teachers in other English schools also spoke to me of such experiences.

Salary is automatically fixed by the Ministry of Education on the basis of age, qualification, and experience. My teaching experience in India was duly recognized. The education office does this job for you and you need not visit their premises even once. There is shown ample consideration for other's time, money had overt concern for his well-being. At my last school, I was interviewed by my Headmistress quite late after the school hours so I had not to take afternoon off from my school. In a few words, she described the whole school and her difficulty in finding a good physics master. She hardly put me any questions like the ones asked at the Public Service Commission interviews. She then showed me round the Physics Laboratory and the school. In my heart of hearts, I thought I might miss the late hourly train. All business concluded, she gave me a lift back to the station and advised me to have a jolly good dinner on the train.

Robbin's report on higher education and Newsom's report on secondary education have pointed out the glaring deficiencies in the British Educational System. Hunger for learning is more perceptible and wide-spread in our country than in theirs. For about the middle 50% of the pupils at the secondary stage, the school still remains a 'bloody school'. Most of them are still at school because of Home Secretary's rule. Their lot has yet to be improved in comparison to the Grammar School children in spite of the fact that each pupil at the secondary stage costs over Rs. 1500 per year to the county. Educational revolution is well ahead now replacing 3 R's (reading, writing and reckoning) by 3 A's (age, ability and aptitude) for all children of all people (2).

Science Teaching in England

Science teaching in England has a comparatively short history. Its origin can be traced back to the last century and a half and even at that time, it did not constitute part of undergraduate courses. British Universities even then hardly contributed to scientific thought. Moreover, response to science courses at that time was quite poor. The state of science teaching of those times can be judged from the following statements.

1. About a hundred years ago, Sir Lyon Playfair emphasized the importance of science teaching in the Primary Schools through first-hand observations, experimentation and manipulation. Children must "question authority and demand proof". He said further that the "whole yearnings of a child are for the natural phenomena around—yet of these he is not taught one fact—as soon as he comes into the school room, all natural God-born instincts are crushed out of him". They are merely "crammed with facts which they vomit forth before the examiner-words have taken the place of concepts". In science teaching this tendency needed to be reversed as he further said, "The pupil must be brought in face of the facts through experiment. He should pull the plant to pieces and see how it is constituted. He must vex the electric cylinder till it yields him its sparks". It is no wonder then that the children fail to answer the 'Commonest scientific question'. Without any

thought, he enters into the world of work. His more telling comment comes when he refers about a committee at the House of Commons engaged in studying the blowing up of the steam engine boilers where a little knowledge of Physics could be more helpful (3f).

2. The great Cambridge Mathematician Todhunter denounced experimental demonstration in Physics. According to him, it has a "demoralising influence on boys". At the same time, he suggested that the boys should "simply trust the teacher's word" (3k).

3. In 1850-52, the Professor of Chemistry gave the following evidence to the then Royal Commission..."there is no residence, museum, library, collection or apparatus attached to the professorship...... and there are no funds for this purpose. There are no opportunities afforded to students for instruction in the actual manipulation of instruments...... Hitherto, the study of chemistry has not only been neglected but discouraged in the University as diverting the attention to pupils from what have been considered their proper academic studies" (3k).

4. A letter dated 11 November, 1859, from the Union of Lancashire and Caeshire, Institute to the Committee on Education shows:—

> "Not to trouble your Lordship with too much detail, I would observe that the utter absence of not only any systematic instruction in science but of any instruction whatever, even for a superficial or desultory character, in the small and large towns of England and even in the great centres of machine making and manufacture, is one of the most outstanding marvels perhaps in the whole history of our wonderful progress as a manufacturing and commercial people" (3a).

Five years later, this situation is further reflected by the report of the Royal Commission on Nine Public Schools in the form of a question addressed to Sir Charles (one of the witnesses) to which he nodded yes......"At all the public and private schools that you know, physical science and natural history are altogether omitted, are they not? Expect such few instances as do not interfere with the general rule''. (3a and 3b)

But at the same time, Faraday, Spencer, John Tyndall, T.H. Huxley, Canon J.H. and Wilson advocated the utilitarian and disciplinarian values of science teaching. Amateurs like Cavendish, Priestley, James Watt and Herchel made great advances in science during the nineteenth century. Societies like the Society of Arts of London (1754), Lunar Society of Birmingham (1766), The Literary and Philosophical Society of Manchester (1781), and Royal Institution of Great Britain (1799) made a big impact on popular opinion. The development of Mechanics Institutes during the eighteenth and nineteenth centuries and finally the Great Exhibition of 1851 really aroused nation's interest in Science and Technology. The establishment of science school at Cambridge (1851) and Oxford (1853) was an important landmark. The founding of Science and Art Department (1870) and the Science Masters' Association and the Association of Women Science Teachers (and both now fused) is the most important factor that has influenced the present day science teaching a great deal.

However, two personalities namely Prof. Armstrong and Mr. Sanderson who made immense personal impact on Science Teaching in schools need special mention in this connection. The former believed that all beginners in science should be put in the position of Original Observers. His aim through his 'Heuristic Approach' to science teaching was to develop "scientific habits of mind, through-fulness and power of seeing, accuracy of thought, of word and action". He even went to the extent of developing actual courses of instruction which were later called British Association Schemes and were, in fact, put into practice in forty schools in London. Later on, after some modifications, his schemes were accepted by the Headmasters' Association. Apart from some artificiality in his schemes of work, his schemes failed to develop the system of exhaustive inquiry as distinct from traditional teaching among the secondary school pupils.

Sanderson, on the other hand, believed in bringing his pupils as quickly as possible to the real frontiers of the subject itself so that they could be easily initiated into solving current problems at that time. In 1917, both of them as members of the British Association pointed out the neglect of teaching of Science as a 'body of inspiring principles and truly humanising influence' which resulted from too much concentration on experimental methods. They further suggested that "History and Biography enable comprehensive view of science to be constructed which cannot be obtained by laboratory work". In 1918, Thomson's report commented on Heuristic Method as follows :—

> "The spirit of enquiry should run through whole of the science work and everything should be done to encourage it, but it seems clear that the heuristic method can never be the main method by which a pupil acquires scientific method and knowledge. He cannot expect to rediscover in his school hours all that he may be fairly expected to know; to insist that he should try to do this is to waste his time and opportunities" (3a).

In conclusion this experience of 150 years has not been a bad educative experience. Formation and information cannot be exclusive or independent of each other. However, these two extreme approaches have resulted in the build up of the "English Tradition of Science Teaching" whose main ingredients are: (1) Reluctance to change, (2) Emphasis on empiricism in contrast to too much theorizing, learning science by personal experience (3) Development of interest and curiosity through imaginative approaches, (4) Emphasis on practical work (individual to group (5) Empirical study of the facts first as compared to specialized and theoretical treatment and lastly the degree of specialization at the sixth form level in schools (3a).

The Nuffield Foundation (April 4, 1962) has now picked up the threads of still progressive science education imaginative enquiry rather than dogmatic assertion, judging evidence rather than memorizing scientific facts and conclusions unreflectively, training pupils to ask questions, to raise questions, to plan experiments and to criticize the evidence offered (firsthand and secondhand) and lastly to concretize the spirit o enquiry, examination and exploration by making it a worthwhile and profitable classroom activity. Attempt is being made to develop suitable courses in "Science For All" for meeting the requirements of both citizens and specialists in the closing half of the twentieth century. Practising teachers themselves are engaged in this task. They are being supported in their work by the consultative committees consisting of persons of high academic repute, teaching aids group and the ministry of education officials. Six different courses are being tackled first—three courses in physics, chemistry and biology for the average and above average pupils in the 11 to 16 age group; science for the average and below average pupils in the same age range; mathematics for those under 13 years of age and lastly science for those under 11 years of age. It may be pointed out here that unlike American projects, emphasis in Nuffield Science Foundation Project is more on the development of imaginative approaches to science teaching rather than the change of content. This is £2,50,000 long-term project. Its first progress report covering work over period of eighteen months was issued by the Nuffield Foundation in October 1963 and is available free of cost from the Nuffield Headquarters in London (3d and 3g). The second progress report has also been published now. The Nuffield material is now available in the market.

Science Teaching in India

It is a paradox that India is a rich country but is full of poor people. And that in its ancient past, it made notable contributions in the fields of philosophy, mathematics, astronomy, medicine and agriculture. It then had a long period of stagnation running over several centuries. As a British colony and all that it implies, it had to miss for historical reasons the first Industrial revolution. Today, when the second industrial revolution (the age of automation) has arrived at the door-step in the west, this country like an 'adolescent in fever' is trying hard to achieve its past glory by recapturing 'its traditions of scholarship and original thinking and its great cultural heritage to participate fully in the March of Science which is probably mankind's greatest enterprise in our times' (4a). In a brief account of this type. it is not possible to give all the details which led to a clerical type of education in this country much of which is still with us today even after twenty-one years of independence.

Our Commitment to Science—Scientific Policy Resolution

The key of the national prosperity, apart from the spirit of the people, lies, in the modern age, in the effective combination of three factors, technology raw materials and capital, of which the first is perhaps the most important, since the creation and adoption of new scientific techniques can, in fact, make up for a deficiency in natural resources, and reduce the demands on capital. But technology can only grow out of the study of the science and its applications.

The dominating feature of the contemporary world is the intense cultivation of science on a large scale, and its application to meet a country's requirements. It is this, which for the first time in man's history, has given to the common man in countries advanced in science, a standard of living and social and cultural amenities, which were once confined to a very small privileged minority of the population. Science has led to the growth and diffusion of culture to an extent never possible before. It has not only radically altered man's material environment, but, what is of deeper significance, It has provided new tools of thought and has extended man's mental horizon. It has thus influenced even the basic values of life, and given to civilisation a new vitality and a new dynamism.

It is only through the scientific approach and method and the use of scientific knowledge that reasonable material and cultural amenities and services can be provided for every member of the community, and it is out of a recognition of this possibility that the idea of a welfare state has grown. It is characteristic of the present world that the progress towards the practical realisation of a welfare state differs widely from country to country in direct relation to the extent of industrialisation and the effort and resources applied in the pursuit of science.

The wealth and prosperity of a nation depend on the effective utilisation of its human and material resources through industrialisation. The use of human material for industrialisation demands its education in science and training in technical skills. Industry opens up possibilities of greater fulfilment for the individual. India's enormous resources of manpower can only become an asset in the modern world when trained and educated.

The above resolution was placed before both the Houses of Parliament on March 13, 1958 by Pt. Jawaharlal Nehru, our late Prime Minister.

We can trace back our present day educational set up to the closing half of the fifteenth century when missionaries (Portuguese, Dutch, Dane, French and English) started coming over here chiefly to preach the Christian religion the European way. The first credit for the same goes to the Portuguese who established elementary schools for imparting knowledge in religion, local language, Portuguese, arithmetic and crafts. For higher education, they established Jesuit colleges which imparted instruction in Latin, religion, logic, music and lastly to train the future bishops. The East India Company finally won the political battle, dominated the natives and from 1858 onwards, India was ruled directly by the British Government in London. With some time-lag, the events there influenced the Indian educational scene. The statement below reflects the distressing state of affairs in the beginning of the nineteenth century.

In a memorandum submitted to the Company, Charles Grant badly deplored the low moral conditions of the Indian people and advised the Company to improve their lot by teaching them the English language which will open to them the vistas of new knowledge. This sorry state of affairs is further reflected by a minute which Lord Minto wrote to the court of directions in 1811 :

> "It is a common remark that science and literature are in a progressive state of decay among the natives of India—the number of the learned is not diminished but the circle of learning even among those who still devoted themselves to it, appears to be considerably contracted. The abstract sciences are abandoned, polite literature neglected and no branch of learning cultivated but what is connected with the peculiar religious doctrines of the people. The immediate consequence of this state of things, is the disuse, and even actual loss, of many valuable books; and it is to be apprehended that, unless Government interfere with a fostering hand, the revival of letters may shortly become hopeless for want of books or of persons capable of explaining them" (4t).

In 1813, a clause was inserted in the charter of the Company which stipulated that 'a sum of not less than one lakh rupees in each year shall be set apart and applied to the revival and improvement of literature and for the introduction and promotion of knowledge of the sciences among the inhabitants of the British territories in India' (4d).

This was a small drop in a big bucket. Consequent on Macaulay's minutes (Feb. 12, 1835), William Bentick stated shortly after in a communique that the British Government should spend its funds on the teaching of European literature and sciences to the Indian people. However, at the same time, indigenous learning was not to be discouraged. Other subsequent resolutions were also passed later. Some notable persons like Raja Ram Mohan Roy advocated strongly the British educational system. The practical aspects of science teaching even then remained practically neglected in the new high schools that were subsequently set up. Upto 1947, many commissions and Committees were set up by our ex-rulers to consider and recommend expert educational measures which remained, largely speaking, unimplemented over the whole century. Wood's despatch (1854), Hunter's Commission (1882), University Act of 1904, Calcutta University Commission (1917), Setting up of the C.A.B.E. (1921-23, 1935 onwards), Hartog Committee report (1929), the Sapru Committee report (1934), the Abbot Wood report (1936-37), the starting of basic education (1937-38), and the Sargent plan on the postwar educational reconstruction and development (1944) need special mention. Up to 1947, the whole educational system lacked quantity (magnitude), quality (depth) and the national pattern or frame of reference (4b). However, some preliminary studies and planning for the future were made in the year 1935-44 so as to visualize a national system of education. In spite of the pious wishes of the people behind all the commissions and committees mentioned above, science education, remained neglected due probably to political pressures.

Many events happened between 1945—1951. Setting up of the interim government at the Centre under the Prime Ministership of Pt. Jawaharlal Nehru, the partition of the country and the attainment of independence, the abolition of the princely states, the famous Industrial Policy Resolution of 1948, framing of the constitution, Report of the University Education Commission, setting up of the U.G.C., and the deliberations on Secondary Education by the C.A.B.E. in January 1948 asking the Government of India to 'review the present position of secondary education in India'. The chief distinguishing characteristic of this period was the detailed educational planning with inadequate implementation. The era of planning then started from 1951 onwards. The educational opportunities for children of all people began to be made available on a large scale. This large-scale expansion necessitated and expedited the emergence and development of a national system of education based upon the recommendations of the commissions and committees appointed after independence. We need hardly remind the readers of the setting up of the Secondary Education Commission (1952-53) in the wake of the University Education Commission (1948-49), the gradual implementation of the constitutional directive regarding compulsory education, declaration of the socialistic pattern of society (1954), the rural higher education committee (1954), the setting up of the educational research institutes like the Central Bureau of Text-Book Research, The Educational & Vocational Guidance Bureau and the National Institute of Basic Education etc. in the Ministry of Education, the Assessment Committee on Basic Education (1955), the National Committee on Women's Education (1958), the establishment of the National Council of Educational Research and Training (1961), and the Kothari Commission's Report (1964-66) for surveying the educational needs of the entire educational system for developing a strong, scientific, technological and economic India. In a way, these deliberations attempted to create a social order founded on the values of freedom, social justice and equality of opportunity for all. In the light of the above events, we had a startling rate of expansion—a primary school within the walking distance of every child and in the age group 6-14, we achieved in fifteen years (1950—1965) about twice the expansion for the preceding 150 years (1800 to 1950) (4e). Through this is a creditable achievement, yet much needs to be done. The experts' remedies to catch up with the times are now continuously going on in a big way. Their influence both qualitatively and quantitatively will, however, take some years not only to penetrate but also to make itself felt.

Science education is not a separate and 'detachable unit' of the secondary education. Its growth has to be seen in the context of the above-mentioned events. Science teaching in

India is several decades old and of course it started on a very slow foot. The reviews issued by the Government of India in the years 1887—92 deplorably reflected the sorry and shocking state of affairs in science teaching of that period. Even up to the beginning of the twentieth century (1904), there was considerable shortage of qualified science teachers. Prof. Armstrong, the world-famous advocate of heuristic method also visited this country. From 1905 to 1917, there was little improvement in the expansion of science education. The first world war also interrupted this expansion. There, however, occurred considerable expansion in secondary education both in the rural and urban areas after the recommendations of the Calcutta University Commission when intermediate colleges in arts, science, medicine and engineering etc. were set up. Since then, the expenditure and expansion of secondary education has been on the increase except during the Second World War when the educational system was just kept going on.

The science education set-up is not exactly the same in all the states of the country. We can still make the following key statements regarding the present day state of affairs applicable to the whole country (largely speaking).

(*a*) Science teaching has been and is still oral in character with demonstrations occasionally thrown in. There is very little of practical work up to the eighth class. At the higher stage, a prescribed list of experiments is rigidly followed by the teachers in the laboratory which is mostly in the nature of verification or working according to set rules which are made quite explicit before the beginning of the experiment to the students. They deviate very little even if they want to, in this respect. Element of investigation, training in the use and practice of scientific method and even mastery of the research operation (discovery approach to learning) are conspicuous by their absence even where the laboratory facilities and equipment are generous.

(*b*) The aims and objectives of science education for the various sciences and at various levels, when spelled out in details look grand on paper. Most of them vaporize during implementation. This then appears to be an excellent exercise in cataloging and exhausting all possible adjectives which sufficiently contribute towards organized confusion in contrast to fusion which is not easy to dispel. General Science is a case in point which so far developed is an 'unstable compound of physics, chemistry, biology and geology' without any adequate thinking, experimentation, integration and any basic theme in it. One finds it very difficult to distinguish the aims and objectives among the various branches of science including general science as such. Too much light by too many experts has produced 'darkness at noon' here. Now, there is a reform in the air regarding the abolition of General Science at the middle school stage. In its place, physics, biology and chemistry will be taught. General Science is more related to the environment than the physics, chemistry and biology taken in isolation. It is cheaper to teach General Science than teaching physics, chemistry and biology as separate and distinct subjects. We try to give a shape before the material is developed in abundance for the same. The lesson to learn is clear.

(*c*) There is no differentiated and sequential curriculum (psychologically or empirically) determined for various categories of students. The old intermediate course has been downgraded over the higher secondary school classes (IX, X and XI) with complete unconcern for the capacities and achievements of the eighth class students. A false impression is being created that increased expenditure and increased curriculum are raising automatically the standards of science education in our country. The overall result is increased failure in science at the end of the higher secondary stage. We will be really lucky if we do not completely damage if not smash our scientific brains at their very critical moments of development.

(*d*) Science teaching is based strictly on the prescribed text-books. Nationalization has killed the very ferment of variety in them. Students and teachers follow them slavishly. The quality of text-books is generally speaking low. Their past persistent defects remind us painfully right up to this day since 1873 when the Government of India passed a resolution about their immediate improvement (4c). In 1964, Dr. Paul Kirkpatrick made a telling comment on the quality of physics text-books being prepared by a Central Committee on Educational Literature in the Ministry of Education :

> "I have read the physics syllabus in its present status and found it disappointing. I also read three manuscript chapters of the proposed physics text-books. The outright errors are capable of repair, but the inferiority goes through the whole process of authorship. The writing is deplorable. Sentences are crudely constructed, exposition unskilful, generalizations unsustained, nonsequiturs frequent. There is not the skilled author's realization of the readers' mental state and the necessity to build the structure of knowledge one little stone at a time, using always the stone that fits.........Is a book by two dozen authors ever likely to possess unity of viewpoint, difficulty, inner relationship, style, or literary clarity ? Now consider that those authors are relatively inexperienced, preoccupied with their full-time job, inadequately compensated, and writing in an acquired tongue. Consider that the chief criteria of selection were degrees, a certain amount of status, and willingness to contribute almost unpaid labour. The criterion of competence was necessarily subordinated" (4*l*).

A sound concept of curriculum materials is yet to emerge in our country which in fact is a must for improved science teaching (Demphasis on text-books).

(*e*) Methods employed for science teaching are dull. They are just short of chanting 'OM JAI JAGDISH'. Here again Dr. Kirpatrick had a telling comment to make—

> "Still on the subject of the difficulties of teacher procurement, one must say that the teachers daily routine is not one to be coveted by the young man or woman of imagination, originality, or desire for accomplishment. I have visited a number of science classrooms in session and been struck by the intellectual sterility of the procedures, a process in which the teacher speaks a few facts or reads them from a book and then asks students to repeat them. The facts themselves are often dull.

Question: What substances burn?

Answer: Only combustible substances burn.

Question: At what temperature does burning start?

Answer: At the ignition point.

Question: Why does not glass burn?

Answer: Because it is a non-combustible substance.

If it be objected that my experience in this classroom was probably not typical I shall at once agree; probably I was shown one of the better classes" (*4l*).

Both teachers and students worship the goddess of examination. The testing abilities of the paper-setters are low. These are the reasons that the science teaching is not related to the environment at all. Consequently, training in scientific method, problem solving, creative thinking and the development of scientific skills, interests, attitudes and appreciations remain in an utter state of neglect. Internal assessment, which could remedy the defects and therefore is desirable, is not only insufficient but also impracticable objectively on a large scale. It still largely remains an external examination in miniature along with its undesirable side effects.

First class methods increase the productive efficiency of the teacher. In our country, the training college methods appear to increase the donkey's work. This ghost of planning and taking everything into consideration complicate the poor teacher's simple difficulties.

(*f*) The academic content of the B.Sc. degree is inadequate. Inferior thinking and action run through the whole professional course. Professional training has very little relevance to the actual class-room conditions. During training, science teachers are not at all trained in the maintenance, repair and construction of home-made and improvised apparatuses. These faults reinforce each other strongly with the consequence that the science teachers fail miserably in creating effective climate of work in their immediate environment over which they do have some control at least.

(g) There is hardly any supervision and availability of expert advice in science teaching by the competent people.

3441

(*h*) There is a complete black-out of research in science education—the little known is really unknown as this author is not aware of the existence of any digest of investigations in science education. The reason for all this is that research in science education is not a rewarding career. Lastly, there is hardly any contribution, pure or applied, by the research scientists and the professors of various sciences in the Universities to the improvement of school science (No Arm-strongs here !).

Ours is a scientific workers' type of education. Innovation and research are not built into it. Science exists, grows and flourishes in a certain socio-cultural environment "with the personal, emotional and intellectual aspects of decision making about science". There is very little of this environment in our country. The explosion of knowledge has rendered the secondary school science courses quite out of date. In the words of Maurice Goldsmith, Director of Science, Science Foundation in London who visited this country recently: "the U.S. physical sciences study curriculum and the U.K. Nuffield revisions are known here but they have yet to make their impact. Too much of science at the secondary school is still concerned with producing contemporaries of Newton and Boyle rather than this century's Einstein and Rutherford" (4r).

Acc. No. 3954

To conclude, the medium of instruction has added to the difficulties both of our teachers and students. History of science is completely ignored in the conduct of science lessons. Increasing sensitivity both to the explosions of knowledge and aspirations throws us back despite our successful efforts to move a bit forward. Explosion of population is straining our intellectual, professional and financial resources to the last bit. Due to the impact of the first three five year plans, the explosion of aspiration and ambition to demand both quality and quantity at the same time has now started gaining magnitude and momentum which in fact is a good sign as it shows our utter dissatisfaction, discontent and intense concern with the shocking state of affairs that prevail today with special reference to science education in particular.

372.3
VAT
S.C.E.R.T., West Bengal
Library
State Institute of Education
Govt. of West Bengal
3441
5.5.75

and secondary education in general. This may eventually alert the nation and compel the entire profession to demand, achieve and deliver the best that it is capable of under intelligent leadership in the not too distant future—which at present is lacking.

Efforts at improvement

It may not be inferred from above that we have all along been unintelligent, unthoughtful and lazy in our educational endeavours. An impressive achievement to our credit is that an increasing number of children is overcrowding the schools and will continue to do so till the constitutional clause regarding compulsory education comes into full operation. The provision of educational opportunities even in the traditional sense for all children of all people is itself a great problem. Moreover, the very backward areas in the country are demanding more and more of quality education. These very essential necessaries and compelling necessities make our educational system a very unstable one. On top of it, we have troubles with China and Pakistan. Thus, despite the best wishes and good-will of the Government, the educationists and the science teachers, our science problems in the context of secondary education become unhaltingly difficult and complex. Even then, it is heartening to note that we have tried hard to lay the basic foundations necessary for building up an intelligent and impressive programme of science education by the end of the Third Five Year Plan. It is about these efforts that we will make a brief mention now.

(*a*) In 1950-51, we had 191·5, 31·2 and 12·2 lakhs of children in the elementary, middle and secondary schools, the corresponding percentages in the three respective age groups (6-11, 11-14 and 14-17) having educational opportunities were 42·6 p.c., 12·7 p.c. and 5·3 p.c. respectively. These figures rose to 496·4, 97·5 and 45·6 lakhs of children and the corresponding percentages in the above mentioned age groups rose upto 76·4 p.c., 28·6 p.c. and 15·6 p.c. in the year 1965-66. In the Third Five Year Plan, the school science has received considerable emphasis. By the end of the Third Five Year Plan, the total number of high and higher secondary schools is expected to go up to 22,000 out of which over 9,000 offer science as an elective subject. The science laboratories of about 6,000 schools will be further strengthened by providing them additional equipment. Moreover, a crash programme now undertaken ensures that all the secondary schools which were opened by the end of the Second Plan will be provided with laboratories 'on 100 p.c. assistance to States by the Centre outside their plan ceilings' (4a, h, i, m and t).

The plan allocation went up from 105 crores of rupees in the First Five Year Plan to 297 crores of rupees in the Third Five Year Plan both for the elementary and secondary education. The above amount excludes expenditure already incurred for maintaining institutions before the beginning of the First Five Year Plan and the contribution from the non-government sources.

It is further proposed to strengthen science teaching both at the elementary and secondary stages : methods of science teaching, setting up of mobile audio-visual units, introducing and strengthening of General Science at the secondary stage, availability of elective sciences at least at one school in an area lacking such facilities and a provision of small science library. It has been proposed to spend a sum of Rs. 500 millions for starting and strengthening science education in its varied aspects. This excludes the provision of Rs. 100 millions for the National Council of Educational Research and Training activities. This expansion and quality in the improvement of science education will naturally depend upon the availibility of competent teachers, laboratory facilities and equipment in them, production of text-books and other instructional and illustrative material (4 '*o*').

(*b*) In the past science meant only physics and chemistry. There was very little of biology teaching in schools. After the recommendations of the secondary education commission, opportunities for biology education became increasingly available in the newly opened multipurpose schools. In most of the states, optional sciences include physics, chemistry, biology, mathematics and geography. Other subjects included are geology (U.P., M.P., A.P., and J. & K.), elements of physiology and hygiene, elements of home science, agriculture, geometrical and mechanical drawing and military science or drawing (M.P. and U.P.). All the states except Kerala prescribe varying degrees of practical work to be done by the students.

General science is taught to all the children in the country up to the middle stage. At the higher secondary stage, it is compulsory in most of the states and optional in Telangana (A.P.), Marathawada (Maharashtra) and Assam. In Bihar, the natural science students do not offer this subject. It is taught for the first two years (IX and X) in the states of Rajasthan, Panjab, Jammu and Kashmir, West Bengal and Maharashtra (Vidharba only). It is taught for three years in the States of Bihar, Kerala, Madras, Mysore and Maharashtra (Marathawada). General science—and not physics, chemistry and biology as separate subjects—is offered in Madras and Kerala. It is only in three states that the practical work in general science is assessed externally (4m).

(*c*) Science needs laboratories and equipment. The Committee on Plan and Projects has suggested Rs. 4000 including Rs. 1000 for tools for equipping the science laboratory at the middle school stage. For a high school, the amount suggested is Rs. 10,000 including Rs. 1000 for workshop tools. Extra grant of Rs. 3000 is suggested if biology is to be introduced at the high school stage. For recurring expenditure on science practicals including replacement, a grant at Rs. 10 per student per year is recommended.

The U.N.E.S.C.O. Planning Mission on Science Teaching has recommended the abolition of General Science. It has on the other hand suggested the teaching of physics, chemistry, biology and astronomy at the middle stage. For this, it has recommended a total grant of Rs. 12,000. Its break-up is as follows :—

	Rs.
Physics	5,000
Chemistry	3,000
Biology	2,000
Geology	1,000
Astronomy	1,000
Total	12,000

At the higher secondary stage, a sum of Rs. 60,000 is considered essential for demonstrations and laboratory work. Its break-up is as follows :

Physics	25,000
Chemistry	17,000
Biology	18,000

At present, the stages of Rajasthan, Panjab and Madhya Pradesh spend Rs. 12,000, 10,000, and 12,200 on physics, Rs. 8,000, 10,000 and 9,500 on chemistry and Rs. 8,000, 10,000 and 14,400 on biology respectively. For General Science and A.V. Aids, Rajasthan and Madhya Pradesh grant additionally Rs. 2,500 and 9,500 respectively.

(*d*) It is a general and common criticism that the teaching of science in the Indian schools is largely bookish and theoretical. Science clubs were first set up in the year 1957-58 by the former All India Council of Secondary Education. There are now about 1000 science clubs and 92 central science clubs in the country. Each science club at the school is given a sum of Rs. 1,200 to augment the school's meagre existing resources only for the purchase of tools and equipment. Their basic aim is to encourage scientific thinking and develop scientific aptitudes, particularly among science students. Their participation, generally speaking, is on the voluntary basis. Their activities range from preparing charts, holding debates and discussions, organizing science fairs in collaboration with other science clubs to the construction of some scientific apparatus and participation on an original project. Dr. Irwin Slesnick, a science consultant at the Regional College of Education, Ajmer, is at present engaged in publicizing through his Science Mobile Show throughout Rajasthan the type of activities which should be initiated and followed up at the science clubs. For practical guidance, he has experimentally developed a book which is expected to provide ideas for science students in some original research projects quite within their reach in the various branches of science. This book is now available free of cost from the Principal Regional College of Education, Ajmer (Raj.).

There are other efforts which directly and indirectly contribute to the quality and improvement of science instruction in the country : Science Competition Essays in vogue in U.P. for the last twenty years, Science Talent Search in vogue in West Bengal for the last six years or so for the first year students at the university, appointment of science consultants in the states department of education for providing expert advice and help to the science teachers for the last seven years or so, appointment of science inspectors in Andhra Pradesh and Mysore for guiding and supervising science instruction, establishment of the four regional colleges of education for producing competent teachers in the fields of science, technology etc. (internship in teaching being their distinctive and distinguishing characteristic) and the State Institute, of Science Education in the Third Five Year Plan and lastly the publications of two journals namely the *Vigyan Shikshak* and the *School Science* published by the All India Science Teachers Association and the Department of Science Education, N.C.E.R.T., New Delhi.

It was about 10 years ago that the All India Science Teachers' Association under the (continuing) presidentship of Dr. A.C. Joshi, at present the Vice Chancellor of the Benares Hindu University and formerly the educational adviser to the Planning Commission, the Vice Chancellor of Panjab University and the Director of Education (Panjab), was formed. The aims and objectives of this association are to improve the standards of school science instruction, to spread scientific information and foster research in the methods of teaching science. It is a voluntary organization and focuses the nation's attention to the various deficiencies in our science education (4*p*).

A comparatively much richer and resourceful nucleus and a department of the National Institute of Education was established in 1961 with a view to changing the total face of science teaching in this country. Over a reasonable period of time, the Department of Science Education aims to generate an effective climate for effective school science teaching. The following are its areas of work :

(*a*) Curriculum materials including textbooks, teachers' guides, laboratory manual, preparation of syllabi and supplementary reading materials etc.

(*b*) *In-service Education.* Summer institutes for science teachers in collaboration with A.I.D. and the U.G.C., to organize workshops and courses for science consultants and science inspectors and the organisation of training courses for the preparation of resource personnal at the elementary level.

(*c*) Publication of the School Science Journal for disseminating information regarding scientific advance, methods of teaching science and book reviews etc.

(*d*) Establishment of science clubs and providing technical and financial help in the organization of science fairs.

(*e*) *Equipment and apparatus.* To provide help and advice in setting up laboratories and purchase of equipment including preparation of suitable inventories for the same.

(*f*) Central workshop for improving and constructing scientific apparatus preferably on the cheap.

(*g*) Laboratory for the department to tackle problems in science education experimentally and consequently to improve science teaching.

(*h*) Organization of workshops and seminars.

(*i*) Instructional materials centre for teaching aids and reference material.

(*j*) Science statistics centre to collect the relevant information.

(*k*) Research in Science Education.

(*l*) Science Talent Search Scheme for identifying gifted students in science at the higher secondary school stage, P.U.C. Colleges and parallel institutions.

(*m*) To provide help to the voluntary organizations interested in science education and organize special programmes like the young scientist's circle, preparation of reading material for the different classes and of special courses for non-science students.

Reports of Commissions and Committees

The Secondary Education Commission (1952-53) was the first Commission in the history of the Indian education to survey the entire secondary education. It recommended the establishment of multipurpose schools which were to provide diversified courses at the end of the middle school stage. Highly qualified teachers and the teaching of specialized sciences at an advanced level were to be the outstanding features of the newly opened higher secondary schools. This radical departure from the past situation created its own problems which were considered by the various commissions and committees later on with a view to upgrading and improving science teaching in all its aspects. In this connection, the following need special mention.

(*a*) About ten years ago (July 15—30, 1956) the All India Seminar on the teaching of science was organized at Tara Devi (Simla) and a document entitled 'Proceedings of the All India Seminar on the Teaching of Science' was published. The terms of reference to the Seminar were : 'to study the higher secondary draft syllabus in General Science, Physics, Chemistry and Biology, to consider Elementary Science syllabus at the primary and middle school levels, to consider the equipment and apparatus for the teaching of science and to plan a scheme of practical work and activities for the higher secondary schools, to test the usefulness of a set of instruments designed by UNESCO for teaching General Science and other elective science subjects in schools, to discuss the methods of examination in these subjects, and to consider science teaching in other aspects like teaching aids, text-books, science clubs and other associated activities etc. The seminar was expected to suggest a sound and uniform scheme of school science education for the whole country taking into account its needs and resources. This was an impossible task but in a way, it pointed out the deficiencies in science teaching, made recommendations and passed resolutions for remedying them (4u).

(*b*) Under the presidentship of Prof. P.C. Mahalanobis, a member of the Planning Commission, a committee was set up by the N.C.E.R.T., to inquire into and recommend measures 'for the improvement and expansion of teaching science at all stages of education particularly at the school level for developing scientific talent in the country and for training of science teachers'. This committee obtained sufficient material relating to the factual position of science education in various states of the country and considered it in its meeting held in July 1962. This document provides interesting information regarding the number of schools offering elective sciences, the conduct of laboratory work at various levels, the number of science clubs and the activities, publications on science teaching and the nature of financial assistance etc. (4i).

(*e*) Early in 1962, the Indian Parliamentary and Scientific Committee under the presidentship of Shri Lal Bahadur Shastri studied and examined the various problems in the area of science education at the primary, secondary and higher secondary stages 'in relation to the policies and decisions arrived at the centre and the states at the commencement of the Third Five Year Plan'. The Committee recognized the gap between what is taught and what should be taught at various levels. Being quite aware of the problem, the committee pointed out that 'quite a number of school buildings are lacking in physical facilities of laboratory equipment, apparatus, library, etc. and the building itself has not been devised from the functional point of view in many cases'. At the same time, it recognized the work being done by the committee on Plan Projects on school buildings, hostels, science laboratories and equipment. (4h)

The report on Science Education in Secondary Schools is the first-attempt of its type to provide information to the educational and administrative authorities about the basic requirements of the science laboratories. This report contains chapters on the financial procedures in force in the various states of the country, science apparatuses and other equipment, planning laboratories functionally and appendices containing information about the recurring and non-recurring grants in different states, procedure for financial sanction for purchase of equipment and apparatus in schools, list of science equipment and apparatus for middle and higher schools and tools and implements required for workshops attached to high schools and teacher training institutions.

(*d*) The U.N.E.S.C.O. Planning Mission under the leadership of Prof. S.G. Shapovalonko stayed in India from December 23, 1963 to March 10, 1964. At the reception given to the members of the mission by Shri P.N. Kirpal, Secretary to the Ministry of Education and the Director of the National Council of Educational Research and Training said that the Ministry of Education would expect the recommendations of the Commission on the following lines:

> 'the objectives and tasks of science and mathematics education in general type of schools in India; the place of science and mathematics in curricula of schools; the content of science and mathematics education, the philosophy of preparation of syllabuses and text-books methods and organization of education; the basic kinds of work to be completed in India before the end of the Third Five Year Plan and those to be fulfilled during the Fourth Five Year Plan period so as to considerably improve science and mathematics education in the country which is necessary for further development of its economy' (4*l*).

The whole report is in six parts. The first part relates to Scientific Technical Progress and Science and Mathematics Education. Importance and implications of recent achievements in physics, chemistry, biology and mathematics for school science have been very well discussed. Part II discusses recommendations for further development with reference to our country; Science and Mathematics education in classes I to VIII; the content of Science and Mathematics education in classes IX to XI; implications of the tasks of polytechnical education in science and mathematics teaching; development of interests, aptitudes and abilities in science and mathematics. Also included are the principles of text-book preparation. Part III contains general recommendations on lay-outs and general equipment of lecture room laboratories in physics, chemistry and biology; teaching equipment in science and mathematics and establishment and organization of Central Science Workshops for manufacturing scientific equipment. Part IV relates to teacher training. Part V is devoted to research in science and mathematics education. Part VI relates to the sequence and the time of implementation of the recommendations and the nature of the Indian specialists to be deputed to U.S.S.R. At the end are appended two papers by Prof. Ralph Buschsbaum and Prof. Paul Kirpatrick on biology and science teaching in India. The outstanding recommendation of the report is the abolition of General Science at the middle stage. In its place, physics and biology should be started in the VI class and chemistry in the VII class.

The recommendations remind us painfully of our extreme backwardness in science. The expert's recommendations are grand but taking all things into considerations, we cannot implement them unaided.

(*e*) 'Mathematics and Science Education', a publication of the All India Science Teachers Association, attempts to consolidate problems in the area of science education facing the country and suggests suitable remedies. The author 'has made full use of the resolutions passed at the annual conferences of the All India Science Teachers' Association held during the last nine years, the resolutions of the conference on science teaching in Asian countries organized by the World Confederation of the organisations of the Teaching Professions held in December 1964 at Manila' his visits abroad and his close contact with the UNESCO Mission on Science Teaching. The book provides some factual information about problems faced, conditions prevailing and the recommendations made by commissions and committees relevant to science teaching at all levels namely primary, middle, higher secondary and teacher training. Organization for leadership is also suggested. A valuable suggestion made is regarding the establishment of science education commission or foundation to tackle most of the problems mentioned in this book and "to play a more effective role in creating consciousness of the right type in teachers, and take such other steps as are found necessary for updating of science education in the country' (4*m*).

(*f*) Our Science Education is really in a bad shape and it becomes worse if we fail to reckon with the explosions of knowledge. The Kothari Commission has pointed out this danger and therefore we have to seek an all time dynamic equilibrium with what all this explosion of knowledge means and implies according to our stage of development not only in our times but also the times to come. To meet this immediate threat, the commission recommends upgrading school curricula by 'research in curriculum development, revision of curriculum based on such research, the preparation of text-books and teaching learning materials ; and the orientation of teachers to the revised curriculum through in service education', where schools themselves have to play an active and intelligent role by devising and experimenting with new ideas that suit them and which cater to the various categories of students at their school. The following six recommendations of the commission are as follows :

1. "In the lower primary classes, science teaching should be related to the child's environment. The Roman alphabet should be taught in class IV to facilitate the child's understanding of internationally accepted symbols of scientific measurement and the use of maps, charts and statistical tables.

2. At the higher primary stage, emphasis should be on the acquisition of knowledge and the ability to think logically, to draw conclusions and to make decisions at a higher level. A disciplinary approach to the teaching of science will be more effective than the general science approach.

3. A science corner in lower primary schools and a laboratory-*cum*-lecture room in higher primary schools are minimum essential requirements.

4. At the lower secondary stage, science should be developed as a discipline of the mind. The newer concepts of physics, chemistry and biology and the experimental approach to the learning of science should be stressed.

5. Science courses at an advanced level may be provided for talented students in selected lower secondary schools with necessary facilities of staff and laboratory.

6. Science teaching should be linked to agriculture in rural areas and to technology in urban areas, but the levels of

attainment and avenues to higher education *will be the same* in both types of schools".

At the same time, the commission has pointed out the importance of the methods of teaching science *i.e.*, emphasis on problem solving, 'investigatory approach and the understanding of basic principles'. Lastly the Commission has recommended the study of science subjects in depth *i.e.*, at the advanced level as in U.K. for the talented students only beginning with their eighth class at school" (4s).

(*g*) *International help*. This is most welcome. At present, we are obtaining help in varying degrees from U.S.A., U.S.S.R., U.K. (The British Council and The Commonwealth Education Liaison Unit) and U.N.E.S.C.O. We send our science personnel abroad and experts from the above agencies visit our country and advise us on the problems facing us. In a way, this is a sign of dependence if we receive too much help from them simply for the asking. Here we should not forget a Tamil saying :

However hard the woman may cry, she has to deliver
the baby herself.

We must learn to solve our problems unaided.

(*h*) *Effective leadership*. Science education in this country appears to be like a living body without a head. The prospects for effective leadership are now brighter than at any time in our past history provided someone is able to give the diverse efforts a shape. In this respect, we hardly need to mention the following : All India Science Teachers' Association, Department of Science Education (N.C.E.R.T.), Departments of Science in the Regional Colleges, Curriculum Panels, the State Institutes of Science Education, the science educators in teachers training colleges, senior science teachers at the multipurpose higher secondary schools and individuals like Dr. A. C. Joshi, S. Natarajan, Dr. S. C. Shukla, Dr. D. S. Kothari and V.N. Wanchoo, to mention only a few.

It is now heartening to note that the Union Ministry of Education is about to establish a National Council for Science Education to upgrade and improve science teaching (other subjects being mathematics, engineering and technology) at all levels with a view to bring them at par with other advanced countries. The agreement in this connection was signed on November 1, 1966 with the U.S.A.I.D. (4v).

Conclusion

The best of work can take place under the worst conditions provided we substitute plans for expenditure by the plans for thinking (productive, creative, original and self-critical) before incurring expenditure. We need to develop (we need not import) and build gradually a sound theoretical frame of reference with our persistent efforts (successful and unsuccessful) which is on a continuum and relevant both to the prevailing conditions and situations likely to prevail within the next thirty to forty years in our country. This frame of reference then needs to be related both to the mentality of our science teachers and students. A first class syllabus, textbook and laboratory in the hands of a frustrated, and an indifferent teacher will result only in chaos and confusion. Narrations, speeches, money and even force do not develop scientific temper which challenges dogmas, superstitions, outmoded ideas, customs and the habitual ways of thinking and action. There are many dimensions including time estimates to this theoretical model as well (*vide* the last chapter).

Failure to develop and understand this model has resulted in the development of unsuitable programmes of science education (near-extinction in case of General Science) for those who constitute the majority and who are not going to use science professionally in their later lives. This argument is also applicable to the development of optional sciences at the higher secondary stage. At the teacher training institutions, we now intend to teach content at the cost of method and education. This is an integrated approach which only few appreciate. We are thus going to rectify the mistakes committed by the universities at a wrong place. The things do not end here. We now organise summer institutes and refresher courses for our science teachers for enhancing their mastery in the content area. The assumptions underlying these new programmes are sound. But there is a general impression that whatever they learn there, is quite irrelevant to their actual classroom teaching. The utilization factor of these programmes is quite low. Now we want to be comprehensive on all fronts. We are becoming near-neurotics (and winners) in a world of our own make-believe quite forgetful of the real situation. We forget that even when money is available, we cannot buy reforms. There has to be some scheme in the total frame of reference. Money alone does not improve the human factor when excellence is built in the hierarchy and not outside of it. We make it a point that we should not provide opportunities, recognition and publicity to our science teachers who struggle with their problems. Understanding, care, discussions on problems and their likely solutions and the committing of intelligent mistakes etc. are rare at the bottom of the profession. Reforms do not climb up—from bottom upwards. Everything comes from the top and the science teacher is at the tap.

Methods of science standardize knowledge and we keep our children ignorant of their knowledge and history. The overall result is that the various interfering factors operate in such a way as to keep the quality (if not the quantity) at its bare minimum. This in fact is tantamount to acknowledging devaluation in science education, Consequently, we then fail to borrow and import assistance according to the stage of our development. For example, do we really need foreign help in developing physics, chemistry and biology for our secondary school students ? There is a limit to dependence. Science teachers at the school should not really function to become only instructors to make the students pass the examinations on courses and examinations conducted by the external agencies. Coaching academies are doing that job excellently.

For all the reasons mentioned above the work of the profession does not become demonstrable enough. Coupled with this is the low salaries which keep the brainy and the interested scientist away from school science. A less ambitious and realistic course of science education may, on the other hand, yield better results and thus avoid the mistakes we committed in the concept of basic education.

CHAPTER 2

Outcomes of Science Education

Education and the Spirit of Science

In the modern world the approach of rational inquiry—the mode of thought which underlies science and technology—is spreading rapidly and, in the process, is changing the world in profound ways .....The spirit of rational inquiry, driven by a belief in its efficacy and by restless curiosity, is.........commonly called the spirit of science.

The terms science is accurate but inadequate. It does not do justice to the fact that this mode of thought related also to questions men usually ask and answer for reasons which they think are totally non-scientific—religious, aesthetic, humanistic, literary. The spirit of science infuses many forms of scholarship besides science itself.

This statement attempts to define the spirit of science and to relate it to education. We believe that a greater awareness of that spirit would lead educators to assign to it a larger and more explicit place among the many goals of education.

The world-wide pursuit and spread of science and technology are commonly recognized. There is less recognition that the values and modes of thought which underlie science and technology also are becoming pervasive in the world. Yet these values and associated modes of thought may in the long run be more important to mankind and to education than the visible fruits of scientific and technological pursuits......science and technology on the one hand arouse the expectation of a better way of life, give promise of material satisfactions, and hold forth greater responsibilities for the development of human potentialities. They give rise to a genuine optimism and excitement. But they also give rise to anxiety ——to a gnawing apprehension of man's alleged loss of personal freedom, of certitude, of psychological security, of identity.

........aware of the apprehensions aroused by the penetration of the scientific spirit, we conclude that the hopes it offers so greatly outweigh the drawbacks as to justify a major recommendation : that a general world-wide fostering of the spirit of science is wise. This conclusion has implications for American foreign policy.

Recommendations

The schools should try to realize the great opportunities which the development of science has made apparent in the world. They can do this by promoting understanding of the values on which science is everywhere based. Although no particular scientists may fully exemplify all these values, they characterize the enterprise of science as a whole.

1. Longing to know and to understand.
2. Questioning of all things.
3. Search for data and their meaning.
4. Demand for verification.
5. Respect for logic.
6. Consideration of premises.
7. Consideration of consequences.

.........these values.........are part and parcel of any true education. These are characteristic not only of what is commonly called science, but more basically, of rational thought.........and that applies not only in science, but in every area of life. What is being advocated here is not the production of more physicists, biologists, or mathematicians, but rather the development of persons whose approach to life as a whole is that of a person who thinks ....a rational person. The characteristics of this mode of thought merit consideration in greater detail.

.........To communicate the spirit of science and to develop people's capacity to use its values should therefore be among the principal goals of education in our own and every other country.

From The 'Education and the Spirit of Science' Published by the Educational Policies Commission, N.E.A., U.S.A., 1966.

Impact of Science and Technology

Within the last decade or so, developments in Science and Technology, have shot sky high. The second industrial revolution (the age of automation) is at our doorstep now and its implications stare us in the face because we do not know much about them so far as their impact on us and our society is concerned—which is lagging far behind. At the same time, the developing countries (generally rich in resources but full of poor people) see in it their only hope of abolishing poverty and in solving problems of food, shelter, clothing and diseases. But even in the European countries and U.S.A. which possess practically most of Science and Technology, there is a widespread concern about "the increase in the scoool population and the prolongation of school attendance, the adaptation of teaching to the new conditions, the extension of compulsory schooling and the guidance of pupils according to their aptitudes and tastes towards those studies which will best develop them and will lead to employment suited to their abilities having regard to the essential needs of the country" (5). Even in England, a feeling is growing that the 'plus' factor of their educational system is fast becoming an outmoded symbol when the words of *The Observer* ring : "The main reason that we are having such trouble coming to terms with the 1960's is that the education in this country is insufficient and out of date—What as a nation we cannot afford is to go on being undereducated. In the economic sense, the expenditure is an absolutely indispensable investment in national efficiency" (6). This problem is much more serious for all of us as is borne out by a Policy Statement in 'Science Education' which says.........

"The effect of science on human life and thought have become so great and are potentially so much greater that those who have no understanding of them and of the science which has produced them, cannot be properly considered educated or truly cultured and are therefore unable to participate in the life of their time. Perhaps scientific illiteracy is in part due to the lack of factual knowledge, but is much more the result of a lack of understanding of the basic nature and aims of science..........Science should be recognised and taught as a major human activity which explores the realms of human experience, maps it methodically but also imaginatively and by disciplined speculation creates a coherent system of knowledge" (7).

If we fail to apply our nerves here, then our maladjustments to the world of science and technology will continue to infest us with some sort of skin diseases with which we have to learn to live till we investigate successfully the casual factors, identify and isolate 'Disarmament' like penicillin in moudly bread.

Self-acceleration of Science

The dissemination of Scientific Information (the introduction of the '4th R') amongst the general masses is a problem which needs to be tackled by us now because such a problem has never been faced in the history of man as we find it today. Naturally, scientific literacy needs to be spread in quantity as well as quality among the masses. We must inform masses effectively about science and technology and their impact on them. The following statements, in this connection, give us an idea about the self-acceleration of science.

(1) Prof. Purcell of Harvard has said that 90% of the world's scientists are alive today.

(2) Prof. J. R. Oppenheimer points out that for the past two hundred years the increase in the number of people engaged in the acquisition of new knowledge, which is the definition of science, is an exponential function of time and the characteristic period is 10 years.

(3) Lord Boyd Orr has said that humanity has seen more progress in the past fifty years than in the preceding twenty centuries.

(4) More than 40,000 papers per week are being added to the literature. (This figure is based upon the world list of scientific periodicals). We are soon approaching a tower of 'Babel' situation as judged by the estimate that 'the average mathematical paper has a ·6 of a reader'. In short, scientific progress, as it appears, follows a "compound interest curve, a curve whose slope approaches a vertical line" (8).

From above, it is clear that we have not to wait for long to see the existing science programme become outmoded in a few years time. The problem in fact does not end here. There is no single definition of science as if it appears that science itself defies its own definition.

What is Science?

Scientific literature on it does not answer this question, either in a single key sentence or a series of such sentences. In fact, it is not possible to answer this question directly because it is not a subject having a well-defined face, say, like that of a chemical crystal. It is not possible to answer this question in terms of common sense alone because common sense may be at variance with tested knowledge. It is not possible to answer this question in terms of methods of attack alone (or the scientific method) because it excludes the knowledge aspect of it and therefore fails to carry us far. Even the decisions making element or criteria in Scientific Method *i.e.*, the nature of inductive inference has become questionable in the domain of atomic physics. Concepts of chance and probability have entered it. It is not therefore possible to give a verdict either way on the truthfulness or falsehood of a particular hypothesis under study when it happens to be partially true meaning thereby "that it would become more nearly so with the adjunction of further hypotheses" (9). It will be a miserly and very poor appreciation of science if it is identified with up-to-dateness, progress, health, happiness, leisure, Beecham's powder and even economic development, as now-a-days conceived in the developing countries. In fact, its essential function is intellectual in the pursuit of knowledge and for its practitioner, its spirit is free enquiry—no sacred cow to worry about either in method or in content when applied to any problematic situation.

In the literature surveyed, definitions of Science have varied from "magic, tricks, health, hapiness, comfort, classified common sense, to deliver a knock out blow in an argument, organized, systematized, precise, accurate, objective, tasted and metrical knowledge (etc.) deducible from a limited number of principles, observations, explorations, experimentation and investigation along with control and comprehension, asking appropriate question, prediction, verification and testing of our ideas against observed facts, discovery of causal systems, experience in search of meaning and thereby develop concepts that make observations coherent and logical" (10).

The following definition of science is quite suitable for our purpose:—

> "In the literal sense, science means the pursuit of knowledge but it has a wider connotation for our purpose, and can be said to mean a knowledge of nature in the widest possible form. This includes nature study, physics, astronomy, meteorology and much more. It is equally important to look beyond

> mere precise definition and see what science includes, and the following are of fundamental importance to the approach to this subject.
>
> 1. Direct and indirect observations.
> 2. Scientific inquiry—asking questions.
> 3. The drawing of inference from evidence.
> 4. Recording observations.
> 5. Developing ways and means to find answers.
> 6. Classification and checking evidence.
>
> Science in fact is more than a subject, it is a method of acquiring knowledge and of necessity the approach must be correct" (11).

Aims of Science Teaching.

From the above, it is possible to deduce the following aims of Science Teaching which are also referred in the relevant literature already surveyed. These are:—

(*a*) Satisfaction and maintenance of curiosity in the environment.

(*b*) Development of accurate observation, also coupled with solving problems through experimentation and drawing inferences from facts and observations alone.

(*c*) To provide initiation and training in scientific method.

(*d*) To understand and appreciate the impact of science and technology on society, its historical and philosophical importance.

(*e*) To identify, to develop, train and prepare for a career in our increasing mechanical civilisation (12).

Outcomes of Science Education.

Looking deeply into the nature of science, its auto-acceleration and its aims of teaching at school, it becomes quite clear that as far as possible, teaching of science to its young consumers should include proposing problems, refining and defining them, setting up hypotheses and their testing with the help of control experiments, thinking out new solutions, discarding personal opinion in the light of new evidence or contradictory evidence and in short, distinguishing between scientific information and popular information and beliefs etc. These initiations and expectations should be brought down to the children's level of experience, comprehension and followed up later on to promote the quality of reasoning as the children go up the school ladder. These visualized behaviour changes among the body of children are referred here as the Outcomes of Science Education keeping in mind the commonsense statement of Victor H. Noll that "The practical objective is not to make everyone 100% open-minded, or 100% accurate or 100% critical (assuming that we know what 100% of these qualities meant) but to make everyone more open-minded, more accurate and more critical then he now is" (13). These outcomes in this light are stated as follows:—

1. Functional Understandings
    - (*a*) Scientific vocabulary.
    - (*b*) Scientific fact.
    - (*c*) Scientific concept.
    - (*d*) Application to new phenomena.
2. Scientific skills.
3. Scientific attitudes.
4. Scientific interests.
5. Scientific appreciations.

Let us discuss these briefly

Functional Understanding

It is not possible to define 'Functional Understanding' in one phrase or in one sentence. It is not even possible to perceive it as it arises in the child's mind, *i.e.* whether it is only a word, a fact, a concept, a principle or something composite called functional understanding. The lines that follow do not, therefore, throw light on this aspect of the problem.

Scientific Vocabulary

It refers to words like mixture, compound, valency, spectrum and electron etc. which are used frequently in scientific literature and constitute an essential part of understanding clearly the scientific thought. The development and knowledge of scientific vocabulary at various grades is essential because only then the children can read and study a paragraph of science with satisfaction, comfort and understanding.

Scientific Fact

It is a statement of an actual event or a physical object. It is mostly empirical in nature. For example:

1. Ice melts at zero degree centrigrade.
2. Heat changes water into steam.
3. Air is not visible to the eye.
4. Sun rises in the east and sets in the west, etc. (14d).

Scientific Concept

Concept is an idea about the environment which may be at variance with tested scientific knowledge. A scientific concept cannot therefore be used in this sense. It underlies, generally, a group of scientific facts. Some of its distinguishing features are:

1. A science concept is not always an isolated fact or even a specific fact about a given phenomenon or object.

2. A science concept is objective in character. It simplifies, classifies, standardizes and inter-relates the various experiences.

3. A science concept explains a certain aspect of the phenomena, certain mode of reaction, or behaviour, or a certain relationship or it governs a group of facts.

4. A science concept is a scientific fact that does not contradict itself without violating some other equally established law.

5. It is a practicable and usable statement specifically worded to be true within its statement (14d).

These considerations apply only for a certain length of time because the fundamental ideas of science also change with the passage of time.

Application to new phenomena

This aspect will be well illustrated in the next chapter under the heading 'illustration of Problem Solving'.

Scientific Skill

This is the second desirable outcome of science education which provides sufficient instructional experiences as regards the acquisition of skills which will function at various levels of proficiency as the growing children pass through successive grades. Of course, the need for background information is a good prerequisite but as regards the development of skills, more emphasis is on interpretation of that much information (*e.g.* learning to interpret the circuit diagrams in electronics), *i.e.*, improvement as regards the methods of work. Knowledge of content alone is insufficient if it is not properly refined by the method *of discovering the additional content and enriching it still further. Stress is, therefore, not on the memory of content but on development, improvement and refinement of tools that manipulate the content with increasing* gains in automatic, precise, discriminating and high grade manipulations as the years go by. The various (abilities) skills (concrete skills, general skills and abstract skills) that can be developed as a result of teaching General Science are mentioned below :—

1. *Concrete skills* (Practical skills) : Experimental skill, collecting skill preservation skill and improvising skill etc.

2. *General skills*. Reading skill, writing skill, listening skill, computational skill and planning skill etc.

3. *Abstract skill*. Ability to recognise and classify things on the basis of common characteristics, ability to analyse simple problematic situations, ability to set up control experiments and from there to distinguish between relevant and irrelevant variables, ability to test and verify one's own ideas, ability to judge absurdities, irrelevancies and fallacies and the development of insight into the assumptions and nature of proof etc.

From above, it is clear that the skills under discussion are characterized both by physical and mental performances because body and mind are two inseparable parts of the same behaving organism (14e).

Scientific Attitude

The third outcome in order of discussion is the formation of scientific attitudes (temper) which is a process that starts right from the very beginning in the immediate environment provided by parents, friends, neighbourhood, school and society at large. Attitude is a 'condition of readiness for a certain type of activity'. Attitudes held by the individuals may be simple or complex, stable or unstable, temporary or permanent and superficial or fundamental. Judgments based upon insufficient facts are likely to yield wrong results and thereby develop biased attitudes. Finding answers to problems through direct observation, adequate experimentation, argumentation on facts, verification and testing of knowledge are some of the initial manifestations of scientific *attitude. Especially for young children, these manifestations need further to be concretized in terms of well-planned teaching situations and meaningful activities.*

This built-in intention in science teaching is more likely to result in the gradual growth of scientific temper among the vast body of school children. Some characteristics of this scientific temper are :—

1. Open-mindedness.
2. Curiosity.
3. Judgment based upon scientific facts alone.
4. Willingness to test and verify conclusions.
5. Faith in cause and effect relationship.
6. Honest reporting.
7. More faith in the books written by specialists in their respective fields, and at the same time, the complete rejection of the principle of authority (14*e*).

Scientific Interest

Next outcome, in order of discussion, comes the importance of interest and their development amongst the body of children while still at school. The teaching of Science should not remain confined to the chanting of facts alone but children should find time and opportunity to make use of them in their leisure time as well. In fact, it is the task of education to see that the children feel alive in the environment in which they live. In this respect, General Science Education is very rich because it provides a great scope and opportunity as regard, the satisfaction of their wants, desires, sense of fun and ultimately the development of their scientific interests. With satisfying experiences, they can find their own special interests and help themselves in their development provided some guidance (not spoon-feeding) is available to them at the science corner. Interests should not be superimposed ; on the other hand, everybody should be free to select the activity according to one's own inner appeal. Interests also change but become stable after sometime. Some of the desirable activities in this connection are :

1. Making collections (seeds, leaves, flowers and minerals, etc.).
2. Making simple preparations (oil, soap and chemicals).
3. Making improvised apparatus.
4. Making scientific models.
5. Setting up some demonstration experiments.
6. Visiting places of scientific interest.
7. Interest in some multifarious activities of the science club.
8. Reading scientific journals and popular books.
9. Describing experiences of scientific interest.
10. Interest in science as a field of vocation (14e).

Scientific Appreciations

Last but not the least, in order of discussion, is the development of scientific appreciation, something akin to appreciation in art, music and literature. William Blake's stricture against Newton, in this connection needs mention : "......for replacing the elephant by a point of mass 'm'; and "denying to man the richness of common experience typifies what is contradictory and vulnerable in our present civilisation. For this reason alone, it is essential to consider how we stand now" (9). Scientists of all races and of all lands have disclosed to all of us the mysteries of nature. Our efforts should not therefore be confined to the teaching of Understandings alone because the concomitant elements of admiration, emotion and intellectual pleasure cannot be altogether easily discarded. It is a part and parcel of the History of Science which is at present characterized by the difficulty of communication in meaningful terms. As pointed out by Wheeler and Perkins, "the intelligence which education is calculated to develop will not grow when uprooted from the background of feeling from which it springs". The scientific content needs to be developed in an evolutionary manner which will impart the tinge of historical development and biographical inspirations and aspirations and will thus provide for emotional satisfactions and develop emotional depth. Some of the areas for developing scientific appreciations are :

1. History of Science, scientific discoveries and inventions.

2. Biographies of scientists.

3. Impact of modern science on daily life and its implications for the future of mankind.

4. Contribution of science to food, shelter, clothing, health and hygiene.

5. Physical environment and environment created by the man.

Understandings and their applications enrich appreciations but cannot be taught like them. Appreciation bereft of understanding is meaningless. Appreciation resists evaluation because it constitutes an intangible outcome of this instruction. Illustrations, narrations, dramatizations, mock ups, field trips and other activities at the Science Corner are some of the factors which will create sufficient experential background. Later on, this can be exploited to develop scientific appreciation because the requisite material has been first created before it has been moulded.

The above-mentioned outcomes of Science Education are, in fact, broad categories which need not only further specific statements about subject matter in a given area of science but also corresponding learning experiences that will help to achieve what has been aimed at in terms of objectives and behaviour changes (for first topic) by making use of community resources. This cuts down the cost of imparting science education as well (14).

CHAPTER 3

Thinking and Problem Solving

Thinking

The development of sound thinking in the school child is the acid test of any first class instruction. Whether attainable or not, this aim naturally ranks quite high with science teachers because they usually do show concern and regard for right concept formation, efficient and improved thinking, problem solving, creative and critical thinking etc. This is true even when both psychologists and science teachers know very little about this mysterious process of thinking which has produced tremendous knowledge for all of us. It is true that thinking is present in all of us to a certain degree but it reaches the level of original invention and discovery only in very few of us. This is why the information-hunters and the book-worms cannot go very far in their advanced thinking in spite of their best and persistent efforts. For these reasons, it is very pertinent to examine a few definitions of thinking or what is thinking considered to be by the philosophers and psychologists from considerations relevant to science teaching and, more particularly, problem solving. The various views on it are mentioned below.

Philosophers and logicians have studied 'Thinking' in terms of its product and have thus developed their laws of thought: Law of Identity, Law of Contradiction and Law of Excluded Middle etc. In a general sense, this term may refer to "guessing, imagining, opining, remembering, reflecting and searching for conclusion" etc. and, in a restricted psychological sense, may refer to "percepts, images, vocal sound, feeling and ideas" etc. Occasionally, it has also been elucidated in terms of "mind, consciousness and judgment". Symmond lists nineteen types of thinking such as learning, meaning, stating relationship, defining and generalising etc., Humphrey equates it with problem solving; for Burt and his students, a hierarchy of thinking abilities comprising relation, association, perception and sensation etc., Gestalt psychologists emphasize the perceptual and problem solving aspect; Bartlet considers it a high level skill in which symbols, words, numbers, shapes, colours, tones—supplement and may take the place of bodily movements. Peel mentions and distinguishes among four kinds of thinking (Thematic, Explanatory, Productive and Integrative) and adds that "Free association, remembering, reverie, fanciful association, punning, solving crossword clues are also other acts of thought that do not fall into these categories". Lastly, Russell develops his own schema starting with stimulus patterns internal or external through materials of thinking (percepts, images, memories and concepts), processes in thinking (perceptual thinking, associative thinking, problem solving and creative thinking act) to products or conclusions implying thereby that abilities in thinking, techniques, habits, and devices etc. can be learned. From above, it appears that it is difficult to define thinking and even when defined, its explanatory terms themselves become suspect and consequently need further explanation (15).

Here, a valuable suggestion has been made by Hearnshaw in 'Recent Studies IN The Psychology Of Thinking' which if followed makes the investigation of 'thinking a profitable enterprise. Thinking then ceases to be a 'ghost' like activity for the purpose of analysis According to him, thinking should be regarded as a skill (or group of skills) which is organization. This point of view is quite consistent with Piaget's genetic findings..."the evidence pointing to the motor accompaniments of thought and the results of perceptual studies emphasizing the dynamic nature of perception and the acquired character of all but the simplest perceptual structures."

With the passage of time, this skill becomes quite complex and is characterised by 'flexibility, transfer, generalization and accurate discrimination processes" which ultimately result in the development of highly abstract conceptual systems, conceptual systems of high order and generality. With this restriction, the attack on the problem of thinking becomes possible. It is then not very difficult to investigate the processes of generalization and discrimination empirically (16).

Productive Thinking

In his book, Wertheimer develops the concept of "Productive Thinking" and clearly distinguishes between structural and non-structural solutions. As a first step for the possible understanding of the process of thinking and the various outside variables that influence it, he advises teachers to develop inventories of human thought processes—a qualitative approach in contrast to factor analysis. His definition of thinking needs to be quoted here (because it seems to the writer to contain clearly the germ of problem solving which we will discuss later in the next section).

> Thinking consists of envisaging, realizing structural features and structural requirements, proceeding in accordance with and determined by these requirements, thereby changing the situation in the direction of structural improvements, which involves.
>
> That gaps, trouble regions, disturbances, superficialities, etc. be viewed and dealt with structurally; that inner structural relations—fitting or not fitting—be sought among such disturbances and the given situation as a whole and among its parts."

Further he empasizes the active role on the part of the problem solver in the thinking process. He is thus sure of an unbroken and undisturbed adventurous and pleasant Gestalt journey. In productive thinking, there is an underlying active process of formulation and reformulation of the problem (17).

Problem Solving

This section refers to the application parts of the outcomes of science education already discussed in the last chapter. Reasoning is an essential part of problem solving which itself is regarded as a complex factor comprising induction, deduction and restrictive or general reasoning (18*b*). We have avoided various controversies on it (reasoning) by including it in problem solving. The various views on problem solving are mentioned below. It may be pointed out, however, that the educational research on problem solving itself has so far been very little.

1. Problem solving takes place as soon as the problem is perceived by the problem solver and is aimed at to reach the goal stated by the problem. The problem is supposed to be not only new and novel but also at the same time, there is supposed to be no direct solution available to the problem solver at the time of its presentation. Moreover, it is also assumed that the problem solver possesses the basic information needed to solve the problem (18*a*).

Definitions of problem solving vary from the "simple finding of exceptions" (Hazlitt) to "formal reasoning of a complex nature" (Piaget). Problem solving has also been defined as "combining the essentials of two isolated experiences" (Maier) or as "the integrated activity of perceptions, memory, recall, association, generalization and reconstruction of ideas" (Welch). Equally different are the problem situations used. They vary from "cats in puzzle boxes or rats in mazes to adult human beings solving complex problems involving space and time relationships resulting in different explanations of the nature of problem solving which are not so much correct or incorrect hypotheses as they are descriptions of behaviour that has been evoked by different types of problems at different levels of difficulty" (15*c*, 19, 20, 21, 22, 23).

2. The basic problem is to generalize from the problem solving behaviour evoked from entirely different problems. Here we should keep the specific characteristics of the various

problems to themselves in order to pinpoint more on problem solving rather than on the psychology (typology) of the problems. Sometimes it is very difficult to distinguish between learning situation and a problem situation because the former does present a problem situation of one kind or the other. Similarly, even the most abstract problem presents certain, aspect of learning: 'from perceived data, trial and error, etc. which makes the distinction quite difficult right at the beginning of the experiment. Learning to tie a knot is a problem when faced initially. Largely speaking, we can say that we speak of a problem when its solution is either by logic or by insight (Munn).

3. Brownell fixes problem somewhere intermediate in a continuum having puzzle type at one end and familiarity and complete understanding at the other end. He also points out the artificiality of 'separating problem solving from other learning tasks because the same objective situation may be seen differently by different persons *e.g.* a puzzle for some, problem and a thorough familiarity for the rest'. In problem solving, the role of memory should be minimum. Lastly, he adds that a problem solver should be able to understand what he is supposed to do while tackling the perceptual and the conceptual tasks embodied in the problems unknown to him. At the time of their presentation, he may experience 'perplexity', but should never experience 'utter confusion' (24).

4. J. Stanley Gray regards problem solving behaviour, of course, a process, but also adjustment with difficulties and interferences encountered in a problem situation. It is a way of proceeding in spite of interferences. He suggests the following methods of problems solving :—

1. Unrelated and habitual behaviour.
2. Insight behaviour.
3. Blind trial and error behaviour.
4. Vicarious behaviour.
5. Behaviour designated as "Scientific Method".

The method of course, depends upon the nature of the difficulty inherent in the problem (25).

5. In classroom situations, problem solving can be viewed from two angles, a way of thinking and a way of teaching. Psychologists have investigated and are interested in the former aspect *i.e.* as a way of thinking which occurs only "when there is a need for it, when the situation is baffling or unsatisfying or when the situation presents a difficulty that cannot be met by other means". The teachers are interested in problem solving as a way of teaching. The research findings from these two angles could well be complementary and highly useful both in the science and art of teaching to the science teachers and their trainers (26 and 27).

After considering the varied views on problem solving, we have tried to disentangle it form three allied areas, namely thinking, reasoning and learning by defining problem solving as—what takes place as task-oriented situation is provided to the problem solver and is aimed at to reach the goal. Moreover, the work task is qualified further by the features that govern the selection of problems stated in the next section.

Logical steps in problem solving

Dewey, on the basis of introspection, has suggested five steps in thinking, which explain 'most of our thinking' which have influenced many others in the field and in their turn have suggested their own steps or stages in the problem solving process. Such steps suggested by the various workers in the field are mentioned below :

Logical Steps

1. **Dewey (1910)**
   - (*a*) A felt difficulty.
   - (*b*) Its location and definition.
   - (*c*) Suggestion of possible solution.
   - (*d*) Development by reasoning of the bearings of suggestions.
   - (*e*) Further observation and experiment leading to its acceptance or rejection.
2. **Burt (1928)**
   - (*a*) Occurrence of a perplexity.
   - (*b*) Clarification of the perplexity.

- (*c*) Appearance of suggested solutions.
- (*d*) Deducing implications of suggested solutions.
- (*e*) Verifying action or observation.

3. **Gray (1935)**
    - (*a*) Sensitivity to problems.
    - (*b*) Knowledge of problem conditions.
    - (*c*) Suggested solution or hypothesis.
    - (*d*) Subjective evaluation.
    - (*e*) Conclusion or generalization.
4. **Johnson (1944)**
    - (*a*) Orienting to the problem.
    - (*b*) Producing relevant material.
    - (*c*) Judging (a critical function) the solution.
5. **Polya (1945)**
    - (*a*) Understand the problem.
    - (*b*) Make a plan.
    - (*c*) Carry out the plan.
    - (*d*) Look back on the completed solution (plus a long list of mental operations).
6. **Humphrey (1948)**

    Directed thinking involves
    - (*a*) A problem situation.
    - (*b*) Motivating factors.
    - (*c*) Trial and error.
    - (*d*) Use of association and images.
    - (*e*) A flash of insight (covers *c*, *d*, and *e* and rests on the problem).
    - (*f*) Some application in action.
7. **Bloom (1950)**

    The four characteristics are
    - (*a*) Understanding the nature of the problem.
    - (*b*) Understanding the ideas contained in the problem.
    - (*c*) General approach to the solution of the problem.
    - (*d*) Attitude towards the solution of the problems.
8. **Burack (1950)**

    Methods of attack
    - (*a*) Clear formulation of the problem.

(*b*) Preliminary survey of material.
(*c*) Analysis into major variables.
(*d*) Location of crucial features.
(*e*) Application of past experience.
(*f*) Varied trials.
(*g*) Control.
(*h*) Elimination of sources of error.
(*i*) Visualization.

9. **Hoffmar and Co-workers (1951)**

Analysis of the Objectives of Problem Solving

(*a*) Sensing significant problems.
(*b*) Defining problems situations.
(*c*) Studying the situation for all facts and clues bearing upon the problem.
(*d*) Manipulating the laboratory equipment needed in solving a problem with understanding of its function.
(*e*) Making the best tentative explanation of hypotheses.
(*f*) Testing hypotheses by experimental or other means.
(*g*) Accepting tentatively or rejecting the hypothesis or testing other hypotheses.
(*h*) Drawing conclusions. Using the hypotheses for generalizing in terms of similar problem situations.

10. **Vinacke (1952)**

(*a*) Recognition of the problem.
(*b*) Manipulation or exploration of some kind.
(*c*) Analysis.
(*d*) Partial solving.
(*e*) Emotional responses.

11. **J. Stanley Gray (1956)**

Methods of Problem Solving

(*a*) Unrelated and habitual solving.
(*b*) Blind trial and error behaviour.
(*c*) Insight behaviour.
(*d*) Vicarious behaviour.
(*e*) Scientific method.

12. **Mills and Dean (1960)**

(*a*) A difficulty is recognized.
(*b*) The problem is clarified and defined.

(*c*) A search for a clue is made.
(*d*) Various suggestions are made, and are evaluated and tried out.

Whereas practice in the definition of problem involves :

(*a*) Problem survey analysing a potential problem situation for items to be studied.
(*b*) Problem description ; providing a clear statement for items to be studied.
(*c*) *Problem discussion* : Making sure that the students understand what is involved in the problem.
(*d*) *Problem limitation* : Isolating those parts of the problem that can be attacked profitably.
(*e*) *Planning for action* : Preparing suitable hypotheses for investigation.
(*f*) *Further analysis and limitation*. Tentative testing of hypotheses to identify those most likely to yield solutions. (15*a*, *c*, *f*, 18, 24, 25, 26, 27 and 28).

The above-mentioned steps in problem solving are not final and need not necessarily follow each other in the problem solving process. They are in fact 'simplified, idealized versions of what may take place in problem solving'. They are "heuristic rather than rigorous proof". There is another view as well.

After the Wurzburg School, many investigators (Dewey Selz, Duncker etc.) have found it convenient to 'see stages in the problem solving processes and in due course of time these stages have acquired a 'natural status'. "Each of this stage has generalized characteristics resembling a learning set" and it was left to Duncker (1945) who 'first elaborated the concepts of set, determining tendency and anticipatory schema from the Wurzburg School into the more generalized concept of search model' called 'Strategies' (Good-now and Austin) or some 'key factor' (Guilford, Merriefield, Christensen and Frick) later on 'in determining efficiency of creative thinking' (23).

Illustration of Problem Solving

From our discussion of problem solving, it becomes clear that every term in the area of thinking needs further self-explanation. It, therefore, becomes very pertinent to concretize 'What problem solving is' by illustrating a few examples.

Before we do so, it will be better to mention the type of problems that can be used for investigating thought processes. The problems can be classified as follows :

(*a*) 1. Explanation
2. Prediction
3. Invention

} Here these have been distinguished in terms of goal.

In the first type, the event is to be explained, in the second type, it is to be predicted and in the third type, it is to be invented by "creating a novel set of conditions that will result in a specified event".

(*b*) It is not a rigid classification. The typology of problems can be distinguished from the following three points of view :

1. The nature and difficulty of the problem.

2. Ways and methods of achieving the solution employed by the subject.

3. The nature of initial and goal situations.

Regarding (3), the problem may be interpolatory (explicit data and explicit goal) or extrapolatory (explicit data but goal is not defined *i.e.* to anticipate consequences). There are two other situations.

(*a*) Where, the situation contains a specific goal but the data are not explicitly defined, *e.g.*

(*i*) Prove that the sum of the angles of a triangle is equal to two right angles.

(*ii*) Why has technology developed so rapidly during the last 60 years?

(*b*) Where there are neither data nor goals in the problem solution. These are referred as pre-problems. These pre-problems can also be further distinguished.

(*i*) Neurotic persons' problems (*i.e.* those who worry too much)

(*ii*) Selection of a problem by a research student (21).

(*c*) Koffka distinguished three types of problems, namely,

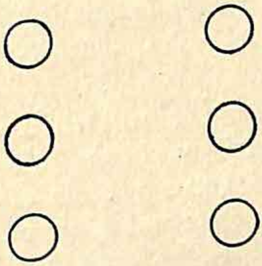
(1) One in which data themselves contain everything that is needed for the process of solution (see Wertheimer and Duncker);

(2) Jokes as used by Harrower and Claparede; and

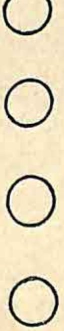
(3) Problems used by Kohler and later on used by various research workers. Koffka further recommended the use of problems that intentionally invite wrong answers. He quotes one used by Harrower.

We may tell a subject like this: Swimming under a bridge there are two ducks in front of two ducks, two ducks behind two ducks, and two ducks in the middle, asking him how many there were in all.

The readers will say immediately that the answer is six ducks. Their answer is based upon the following organization:-



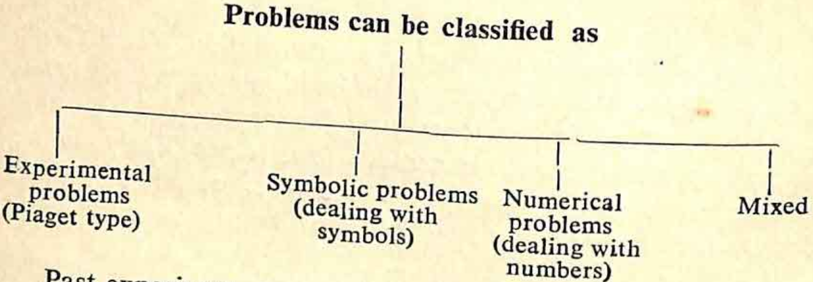
This, of course, is not the correct solution. The above mentioned problem does succeed in inviting a wrong answer—a pair is implied in the concept of twoness (3×2=6). A single aspect file, even if it strikes a few, is not likely to be considered at the first attempt. The correct solution is four ducks which can be judged by the following organization:



A systematic employment of this method should reveal a number of factors which determine organization in thought processes (29). Sayal and Vaidya used this technique for investigating problem solving in arithmetic among three distinct groups of sixth class students, group *A* being the top group, *B* the average group and *C* the bottom group. They found that with respect to the category *X i.e.* problems inviting wrong answers intentionally, the difference between means for the groups *B* and *C* is not significant ($t = \cdot 60$) but between the groups *A* and *B*, means is significant at 5 per cent level. This means that the top group is influenced less by the content of the problem inviting wrong answers as compared with both groups *B* and *C* (30).

(*d*) A much easier classification is based upon topics *i.e.*, all problems which deal with decimals are put together in one category (22).

(*e*) Personal experience will tell any investigator that it is very difficult to classify problems into clear-cut categories especially when they involve a chain of reasoning which can be pitched both at concrete and abstract levels. The following classification, in this light, can also be considered.


Problems can be classified as
Experimental problems (Piaget type)
Symbolic problems (dealing with symbols)
Numerical problems (dealing with numbers)
Mixed

Past experience, approach to the problem and demand of the problem may also effect the typology of problems in certain cases. It may then become either a new type test item, a traditional question, a thought problem or a research problem requiring a lot of concentration and a long time to solve it. A suggestion may be made here that the problems should be classified in terms of hypotheses likely to be tested in the study (See the analysis of problem solving processes in our experimental study of problem solving) (28).

Selection of problems

The choice of a problem is very important in investigating thought processes. A problem, carefully selected, initiates thinking in different directions. For selecting such problems, the following criteria should be kept in mind :

1. The reading difficulty of the problem should be low.

2. The problem chosen should be neither too difficult nor too easy. If possible, it should be based upon the daily experience of the children.

3. It should be as far as possible new and novel to most of the students. At the same time, they should possess all the basic information needed to solve the problem.

4. It should not be too bookish. It should not demand much specialized knowledge or information. At the same time, it should be as diverse as possible, general, perplexing, demand thinking and provoke action. At the same time, it should not at all produce utter confusion or 'mental dazzle'.

5. Every pupil should be able to solve at least part of the problem; and

6. Lastly, the problem should provide for :
   (*a*) Setting up hypotheses and their testing against the data.
   (*b*) Inclusion of qualitative, concrete and formal solutions which may even end in mathematical generalizations and its application.
   (*c*) For crucial elements and
   (*d*) For gradual development and growth of the solution.(28)

Illustration of problem solving

Experimental problems : (*11 plus onwards*)

You are given a battery, one bulb, and some one-way and two-way switches and some connecting wires. Your problem is to find a circuit enabling you to switch on and switch off the given bulb from two different points.

The background information needed for this problem is the working knowledge of one-way and two-way switches. The general experience with this problem is that it is neither too difficult nor too easy but is rather quite awkward to solve. The solution consists in getting at the idea of a parallel circuit.

Problem 2 (*12 plus onwards*)

This depends upon the application of the laws of reflection and knowledge of the angle of deviation. The concrete part is easy but the formal proof is reached in the sixth form only.

A ray of light falls successively on two plane mirrors held at an angle (not necessarily touching) and thus suffers reflection twice. It is then deviated from its original path. The angle of deviation may depend upon :—

(*a*) Angle of incidence.

(*b*) Distance between the mirrors.

(*c*) Length of the mirror.

(*d*) Angle between the mirrors.

The factors (*b*) and (*c*) caused difficulties and had to be dropped. The problem is then solved concretely that angle of deviation is equal to twice the angle between the mirrors and is independent of the angle of incidence. To avoid experimental errors, hypothetical data can be supplied. The problem still involves setting up hypothesis and testing them against the given data.

Symbolic Problems

In this case, the problems deal with symbols but are not in fact hard exercises in algebra. They are quite suitable to the sixth formers taking up *A* level physics. In many cases, when the problems appeared to be too difficult, the demand of the problem appeared to be met by starting the solution backwards. The problems turned out to be quite time-consuming but they do throw light on the problem solving process. Two such problems are now mentioned.

Problem 3 (*16 plus onwards*)

A mass of M pounds rests on a smooth horizontal table and is attached by two inelastic strings to marks m and m' ($m' > m$)

which hang over smooth pulleys at opposite edges of the table. Show that the acceleration of the system is :

$$f=\frac{m'-m}{m+m'+M}\times g$$

Problem 4 (*15 plus onwards*)

A convex lens casts a real image of a candle flame on a screen. The lens is displaced through a distance x (the candle and the screen remaining fixed) until the image on the screen is again sharp. Show that the focal length of the lens is given by $\frac{1}{4}\left(d-\frac{x^2}{d}\right)$ where d is the distance from candle to the screen.

Numerical Problems

In this case, the problems deal with numbers but they are definitely based on some scientific application of some known law or principle. They test more than the computational ability. Two such problems are now mentioned.

Problem 5 (*16 plus onwards*)

A small luminous body 100 cm. deep emits rays upwards in all directions. A circle of light is formed at the surface of water by rays which are refracted into air. Beyond this circle, the rays are reflected back into the tank. Find the radius of the circle ($\mu=\frac{4}{3}$).

Problem 6 (*14 plus ownwards*)

A boy drops a pebble down an empty well and hears it hit the bottom after three seconds. He shuts down the well and hears the echo after $\frac{1}{4}$ second. The speed of the sound is 1058 ft./second. How long does the stone actually take to fall from top to bottom ? How deep is the well ?

In this problem, the time taken by the stone to fall from top to bottom can be calculated in two different ways.

Mixed Problems (*16 plus onwards*)

In this case, the problem involves symbols as well as quantities. These problems are generally comparatively easier than the symbolic ones but they do involve seeing relationships.

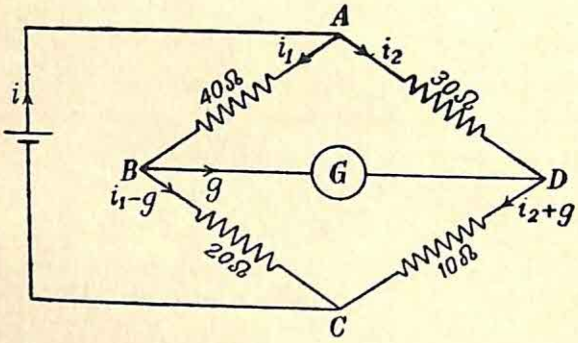
Problem 7 (*15 plus onwards*)

When two long magnets are arranged with their axes along the same straight line so that their north poles face each other at a distance of 6 *cm.*, a point of zero intensity is found 2 *cm.* from one of the poles. What is the ratio of their pole strengths?

If the field intensity midway between the poles is 5 dynes per unit pole in a direction towards the weaker pole, what are the individual pole strengths of the magnets?

Problem 8 (*17 plus onwards*)

It is based upon Kirchoff's laws and the problem is to find current flowing in the galvanometer when the given bridge is unbalanced. The diagram is shown below.



Concluding statement

We have attempted, in this chapter, a working definition of problem solving by deliberately avoiding terms like concept formation, creative thinking, critical thinking, insight and learning. We have also pointed out the place of reasoning in problem solving. If the problem solving is tied to the task, then the nature of the task itself becomes suspect. We have, therefore, suggested the necessity of using problems as diverse as possible. This is not even sufficient. We have, therefore, further developed multiple criteria for the final selection of problems which may finally help us in investigating assumptions underlying thought processes. Lastly, the final test for the selection of the problem is by its actual administration on pupils varying in age, intelligence and achievement.

The concept of stages or steps is shown in its proper perspective, *i.e.* it is done for convenience only. The steps or stages as such do not clarify any psychological principles because it is possible to find stages in any problem. Piaget has, of course, given his commentary on the basis of some selected protocols right from the pre-operational stage to the logical stage by seeing all the stages in perspective. Even then, the content aspect of the problem has not received adequate attention. This appears to be the reason why factor analytic studies have failed to support Piaget's ideas. In this respect, Inhelder has pointed out the following two conditions which must be met before we can attempt to verify his (Piaget's) ideas:

1. "The response to a given problem shows a constructive and constant change with age.

2. That a group of the problems formed a Guttman scale" (19).

Lastly, longitudinal studies are still needed to confirm our ideas finally about the theory of problem solving that may eventually result from such studies.

STATE INSTITUTE OF EDUCATION * Govt. of West Bengal.

S.C.E.R.T., West Bengal * Library * Calcutta 25/3, B. C. Road

CHAPTER 4

Survey of Human Problem Solving with Special Reference to the Teaching of Science in the Light of some Theoretical Considerations

In this chapter, we attempt an up-to-date survey of human problem solving with special reference to the teaching of secondary school science. In this context, all studies relating to animal studies, thinking (autistic, associative, creative and critical relationship between language and thinking, concept formation (including concept attainment, abstraction, generalization), memory, imagination, attention, believing, judging and rival theories of learning etc. are excluded from consideration straightaway. Exception is made only where the reference is relevant or incidental. Lastly, the whole area of problem solving is reviewed not only from a theoretical angle, but important researches conducted abroad are also reviewed. The relevant literature is examined further in its strengths and weaknesses.

It will not be out of place to mention the outstanding conclusion at this place which emerges out of this survey.

Since the beginning of this century, we are not very far from the starting point even to-day. This hit-and-miss experience has really not been so futile as it may appear to be because today we know the kind of road we have to traverse which we did not know at the beginning of the century (31).

Problems yet to be investigated

The field of problem solving as a whole still poses certain problems that are yet to be investigated before we can fully understand the basic assumptions underlying human thought processes. It is very likely that the answers to these questions will have an import equal to the concept of Periodic Table in chemistry or the concept of Quanta in atomic physics for the whole field of psychology as well. Let us now consider the problems posed by the various workers in this field.

(*a*) *Cohen*. The role of past experience in the thinking of an individual has been investigated very little. 'What makes people attack problems' will contribute to our understanding in this area (32).

(*b*) *Johnson*. An adequate understanding of problem solving requires "knowledge of the development of even higher organisation (as compared to concept formation) of data such as the concept of self, points of view, frames of reference, and more complex patterns of inter-relationships illustrated by the family pattern, the syllogism and the pattern of industrial expansion." A full psychological description of problem solving will reflect the "attainment of the mastery of such materials". He suggests that the study of individual differences in thinking in relation to the other personality variables would be quite worth-while (33).

(*c*) *Vinacke*. The whole area is open for investigation. For penetrating analysis in this area, he suggests the case study approach as the best method for yielding results. It may then be possible to know whether any common patterns of thinking exist for individuals or unique thinking pattern is characteristic of each individual. An experimental approach in a broad frame of reference, and whereas many variables as possible are considered, is needed to answer these questions (34).

(*d*) *Duncan Carl P.* The whole area of problem solving has been loosely developed. He then stresses the position of Ray and Underwood : "Although theoretical developments are not necessarily unwelcome, the basic need in problem solving is experimental determination of the functional relationship between dimensionalized independent variables and problem solving performance" (35).

(*d*) *Wheeler D.* It is strange that in our highly scientific world the study of thinking processes underlying scientific reasoning has received scant attention uptill now. The reasoning processes of supernormal children particularly need urgently to be investigated (36).

(*e*) *Geneva School. Piaget and Inhelder* have emphasized the importance of investigating logical thinking among children and adolescent pupils. Their contribution in this field is itself quite monumental. The educational implications of their work are still under study (37).

(*g*) *Peel.* In his book 'The Pupils Thinking', Peel makes out an emphatic case for undertaking studies in terms of Piaget's and Dunckers' theories and experiments in the area of problem solving. Further, the generalization of essential reasoning power in one area to all other areas is little understood even today (38).

(*h*) *Ennis R.H.* Dealing with a concept of critical thinking, he points out the gap on thinking in the field of psychology and education. Even now, the role of outside variables like set, motivation, aspiration and ego involvement etc. is quite obscure. Thus more difficulties arise for the workers when they attempt to dig deeper in this area (39).

(*i*) *Travers.* If one goes through the relevant literature on problem solving, it appears that the whole area lacks a theoretical frame of reference (40).

(*j*) *Watson.* While reviewing research on science teaching with special reference to the methods of science teaching, he says that there is very little research on "the relationship between the behaviour of science teachers and other variables such as the behaviour of their pupils". We have yet to gather clear-cut empirical evidence on the relationship between "the quality of experience" and the consequent behaviour changes ensuing from it" (41).

From above, it is clear that there are many difficulties which need to be tackled before we can understand clearly the area of problem solving including thinking. The difficulty lies in failure to understand the sequence of reasoning from early childhood to late adolescence, the relationship between the various characteristics of problem solvers and problem solving under various situations and the role of past experience in the solution of the problem. This difficulty does not end here because there is no commonly agreed definition of problem itself *i.e.*, "what is a problem ?" Despite this, there have been a few theoretical attempts and some good research studies in this area which have relevance for science teaching.

With this as the background (mostly as problems), we will now survey the whole field under the following heads :

Section A

(*a*) Maltzman's theory
(*b*) Programmed learning
(*c*) Gestalt School
(*d*) Phenomenological theory
(*e*) Geneva School
(*f*) Acceleration of mental development
(*g*) Factor analytic approach
(*h*) Information processing.

Section B

Significant researches on problem solving and problem solving in science are mentioned in this section.

SECTION A

SOME THEORETICAL CONSIDERATIONS

From the practical point of view, the concepts of conditioning and reinforcement for initial learning including teaching of skills are very useful at the beginning of the learning process. However, these concepts do not go far enough to explain the higher process of thinking *e.g.*, original thinking. According to Pauli, the aim of science teaching is not only the acquisition of information and skills (of course, this is desirable) but also to "attain the understanding of the relationship which concepts the answer to the problem" (42).

(*a*) Maltzman's theory.

Maltzman has propounded a full description of thinking from the behaviouristic point of view. It is based upon *S-R* theories and takes its cues from the studies of Hull. He suggests a compound temporal hierarchy which covers "divergent trial and error mechanisms and the convergent, discrimination learning mechanism". Regarding reinforcement (or extinction), its effect is not localized *i.e.*, confined to a particular member alone but supposed to generalize to the other members as well. Mediated generalizations is a basic idea in his theory which is accomplished by linguistic responses. The role of anxiety, failure to solve a problem, failure to overcome a set and the recurrence of interfering responses are fully explained by his theory. According to him, training in original thinking is possible provided suitable techniques are devised which bring about that type of infrequent or uncommon behaviour considered relevant to those conditions. His theory, however, fails to explain such tasks as the two-string problem (Maier) but yet it is one of the most fruitful theories in problem solving. His ideas have been further extended by Cofer (1957), Judson and Cofer (1956), Judson, Cofer and Gelfand (1956). All of them emphasize "the role of verbal responses as mediators in response hierarchies" (43).

(*b*) Programmed learning.

Programmed learning (instruction) is not a new idea in our times *e.g.*, Pavlov's experiment on dogs, E. L. Thorndike's systematic topic analysis in school subjects, his laws of learning, particularly, his law of effect, diagnostic testing and teaching based on it especially for backward children (Burt and Schonell's work) and the conscious and unconscious effort of the practising teachers to state the objectives of teaching their subjects more specifically and assessing them more objectively and thereby to choose right learning experiences and tasks suitably graded including practice exercises. Skinner (and his co-workers) developed the basic ideas of programmed learning (instruction) from his investigations in the area of animal learning. The most important notion in it is that of immediate reinforcement. According to him, it is possible to teach advanced skills to rats, cats and pigeons etc. which they did not possess before the beginning of the experiment by breaking the advanced skill into the smallest possible bits and choosing the most relevant and meaningful stimuli and responses which fit into each other like the various links in a long chain (conditioned view of advanced learning). For achieving these purposes, advanced electronic equipment came handy to him. Thus he was able to teach pigeons, for example, to dance in intricate patterns or to play pingpong game till their beaks bled profusely. The activity itself appeared to motivate the pigeons to continue the game for quite a long time. According to him, class-room learning is deficient because the correct responses are not adequately reinforced at the proper time. Thus he arrrived at the basic notion of reinforcement (immediate reinforcement and the conditions surrounding it) and applied it successfully in the so-called teaching machines now getting quite popular in some advanced countries like U.S.A., England and U.S.S.R.

Let us consider the following two examples :—

(*a*) Suppose, we wish to teach the spelling of the word 'manufacture'. A suitable little introduction and instructions are given successively to motivate the pupils and directing their attention to the position of important letters or a group of letters (Fact) in teaching the spelling of the new word. The programme for teaching the spelling of this new word is something like this :

(*a*) Copy this word	MANUFACTURE
(*b*) U comes between N and F ; now complete the word.	MAN★FACTURE

(*c*) U also comes between T and R and now complete the word M A N ★ F A C T ★ R E

(*d*) U comes twice *i.e.* between letters N and F and T and R. Again complete the world. M A N ★ F A C T ★ R E

(*e*) There is the word Fact in the spelling of the word. M A N ★ ★ ★ ★ ★ ★ ★ R E

Similarly 'man', and so on till all the cues are made to vanish gradually.

(*b*) Matter is made up of atoms. Table is matter. So table is made up of

atoms

Similarly brick is a matter. So brick is made up of......

atoms

Brick and table are matter. Each of them occupies space and possesses weight. Therefore matter occupies..................and possesses....................and so on

space and weight

Different versions and many variations within the same version are possible depending upon the specific objectives to be achieved, the nature of the pupils and the expertise of the programmer. The pupil himself reacts bit by bit to the whole programme as the amount of information presented at each step is very small. He thus learns what he is expected to learn by the programmer without the help of the teacher. The very working on the machine, the varied type of stimuli in the programme and the immediate knowledge of the results continue to motivate the pupils to a very high degree. Right responses in the teaching sequence are immediately reinforced. In an ideal programme, a pupil is sure to emit a correct response all the time. There is nothing wrong with the pupil if he fails to learn. The fault lies with the programme itself. It needs to be further rectified by repeated trials till above 90% of the pupils are able to learn the entire programme.

Lastly, it is possible to programme anything, theoretically speaking, that can be verbalized say in language, mathematics or science.

Programmes so far developed have been criticized on the ground that they fail to develop literary appreciation, constructive imagination, thinking (critical, creative and original), emotional and artistic sensitivity and in no way at all help a student to memorize a long poem etc. Of course, for the teacher, part of the donkey's heavy load is unburdened to some extent. Controversies still centre around efficacy of errorless learning, utility (immediate and ultimate) and desirability of the immediate reinforcement, amount of information contained in the step, the structure of the programme itself (linear or branching), role of anxiety and frustration (their importance and significance) in learning (Bugelski, and Water-house and Child) and exclusive use of verbal materials alone. Researches will answer these problems in due course of time but it is still possible to achieve the objectives of teaching by emphasizing programmed methods (techniques) if we do not bother ourselves too much with the above-mentioned controversies. Teaching sequence is strengthened (provided we know its weak points) if we choose and use different types of learning tasks (and presentation medium) suitably graded *e.g.* maps, pictures, practical work, paper programmes, models and tape recorders. In the light of objectives, we can train our pupils to react educatively on their own to these learning tasks. This is the first step towards self-education and programmed techniques rather than programmes which as understood and available today show a great promise in the near future (43*b* and *c*, 44).

(*c*) **Gestalt School.**

Wurzburgers were the first to investigate thought experimentally. For this they developed their own method called 'systematic or experimental' introspection. They were not much interested in problem solving as such but confined themselves to such questions as 'what is the consciousness when we are thinking of ? Why does a subject start thinking?". They therefore considered consciousness as passive entities govern-ed by logical rules. They did not distinguish between productive and reproductive knowledge (or thinking) as the same laws applied to both. With the appearance of a comparatively more fruitful and productive model, the whole approach of the Wurzburg school fell "like a house of cards silently and without any resistance" (48).

This productive model was the Gestalt psychology which was first propounded by Wertheimer in 1912. This school violently attacked the prevailing association psychology (structuralism, functionalism and behaviourism) then prevailing in America. It is interesting to note that this Gestalt school is also deeply rooted in philosophy and physiology. Further, it also attempts to contribute to the 'integration of matter, life and man'. Thus speculations, for these two reasons, entered in Gestalt psychology which provided opportunities for the behaviourists to attack Gestalt psychology quite fiercely.

The following are the important features of Gestalt psychology :—

(*a*) Laws applicable to perception extend to thinking as well as to the objects of thought.

(*b*) It is neither additive nor summative, neither product nor process. It is a 'prime fact of experience' like the concept of molecule in chemistry which does not share the properties of the constituents composing it.

(*c*) Behaviour always takes place in an environment. Psychological processes operate in the present (prevailing) field which are subject to Gestalt forces.

(*d*) Role of past experience and memory is minimally stressed (40 to 51).

Wertheimer, Koffka and Duncker have emphasized the dynamic nature of the field and stated the major problem of thinking. With reference to science teaching, two basic notions appear to emerge from their work, these being productive thinking and insight. We will elucidate these two concepts by referring to their work in brief.

Wertheimer

Being dissatisfied and finding inadequate the existing approaches of traditional logic and association theory, he posed to himself the following problem and then attempted to answer it himself. Throughout his discourse, he was quite aware that every word in his statement contained a potential problem for further investigation and research.

He asks : What takes place (occurs nnd happens) when thinking moves ahead and works productively. We cannot answer this question for the simple reason that we cannot observe these thinking processes directly as they go on in the mind......their birth, their decisive features—the basic steps, the flash and the spark etc. He goes on to speculate about conditions both favourable and unfavourable that influence attitudes towards good (or bad) thinking and the methods of improving thinking. Lastly, he distinguishes between structural and non-structural solutions when he discusses some problems relating to parallelogram, sum of the angles of a polygon and the summation of series which are quite well-known in literature (47). In this very thought-provoking discussion, the very transition of a non-structural to the structural solution remains obscure (at least to this author).

Koffka

He posed to himself the following question and failed to answer it : How does the problem attempt to resolve itself and find its answer ? How does the stress set up by it attempt to create conditions which make the answer to the problem possible ? It should be remembered that the "arousal of a new process is not in all cases a problem of traces". The immediate cause is still shrouded in mystery. Wertheimer, Duncker, Maier and Claparede have all along recognized this problem (45).

Karl Duncker

He investigated the thought processes of University students by using practical type of problems which had clear-cut solutions. His main aim was to find out how and in what manner the solution of a problem arose from the problem itself. According to him, there is a problem when one has a goal but does not know how to attain it there is then 'recourse to thinking'. Two of his world famous problems are now mentioned.

Tumour Problem

Growth of the problem solving process

(*a*) **General Range**	Avoid contact between rays and healthy tissues	Desensitize the healthy tissues	Weaker intensity of the radiation on their way through healthy tissues
(*b*) **Functional Solution**	1. Use free path on the stomach. 2. by removing healthy tissues from the path of the rays etc.	(*a*) by injecting desensitizing material. (*b*) by immunization to weak rays	1. Postponement till full intensity is reached. 2. by concentrating rays at the centre of the tumour somehow.
(*c*) **Specific Solution**	Suggestions based upon the above.		Use of a lens solves the problem specifically.

1. *Compensated pendulum.* You have seen a pendulum. The slowness or fastness of the pendulum depends upon its length—the distance between the point of suspension and the centre of gravity of the bob. In winter, this length decreases and the clock goes fast and *vice versa* in summer. But we want the clock to run with absolute accuracy. How can this defect be remedied ? Lastly we are "only concerned with the length of the pendulum, the rest, the pendulum may have any appearance at all".

2. *Stomach tumour.* There is a patient suffering from an inoperable stomach tumour. Radiation at different intensities is available. The problem is to treat the tumour without destroying the healthy tissues surrounding it. What can be done ?

The experimental procedure employed is simple. The subject is asked to speak about the various ideas (stupid and foolish) that strike him during problem solving. The subject is free to question the experimenter whenever the former does not feel completely informed about the problem. This dialogue continues till the problem is solved partially or fully.

The basic analysis of one such complete protocol in its basic essentials for the second problem is shown on the opposite page (46 and 49).

It will be of interest here to refer in brief to the solution of another problem (simple pendulum) in which each subject (fifteen year old pupil in Central London) was asked by this author individually to suggest and set up control experiments so as to determine the length of the string as the sole relevant variable out of the other irrelevant variables like weight of the bob, size of the bob, and amount of amplitude etc. which influenced the time period of the simple pendulum. Then the solution of the problem for the entire sample ($N=31$) was seen something like this—

(*a*) *Extraneous and arbitrary considerations.* No solution was given by 16 pupils but one could find extraneous and arbitrary considerations entering their responses: Some characteristic responses were :

> 'Guess weight of the bob is 4 ounces (control weight factor) and radius $\frac{1}{2}$ inch (for volume you

> know). Cut off the bob and cut off the string (then there is no problem at all). You make it smaller and longer. The pendulum goes fast and it goes slower. With heavy bob, it goes slower. Measure the swing. Yes but I was in fact thinking of the policeman (bob !) all the time (Confusion of words). Get a cup of water and I find its volume. (Control of volume). The moving bob will injure my eyes. It is stupid to see the ball going like this. It goes as much as you like (control amplitude factor). You can stop the bob. I look stump on this problem'.

While engaged in solving this problem, many extraneous and arbitrary considerations turned up from the academic group right down to the remedial group. These considerations were quite irrelevant to the solution of the problem but were given by all categories of pupils.

(*b*) *Grasping the essence of the problem.* Fifteen pupils showed the awareness of the fixed time (control time). Only seven out of them were able to suggest control experiments which excluded the above-mentioned three irrelevant variables.

Those who have solved this problem became aware of the importance of the fixed time (or count) after a few trials of the demonstration experiment itself. They are then asked (individually) to explain the consequences of the control experiments. The way they make judgements is more important to us than the recording of actual observations. The latter are in fact discouraged if they do not support or reject their sequence (chain) of reasoning. It is immaterial to our consideration whether they calculate time for one oscillation or always keep the number of oscillations fixed.

Choosing suitable bobs turned out to be quite difficult. Concepts of bobs having same weight but different volumes and *vice versa* tended to block their thinking for a long time. They sat silently with pencil in their mouths and appeared to have turned deaf even when asked : "What are you thinking now ?" They all appeared to be forgetful and then started stating their methods. They felt lot of difficulty in expressing their methods and sometimes their chain of reasoning was so fast that it was very difficult to follow. For our purpose, they appeared to have grasped the essentials of the problem when questioned thus :

For getting rid of the weight of the bob, you will take string of what length (lengths). What about amplitude ? What about volume ? What about count ? (For the statement of this problem, see the next chapter).

The following conclusions emerge from Duncker's studies.

1. One solution is as good as any other so far as the 'way out' of the problem situation is concerned. What is reflected in fact is the degree of the acceptance of the demands of the problem. Extraneous considerations enter into the problem situation when the essential aspect of the problem is not grasped.

2. Duncker then distinguishes between functional solution and the specific solution. The functional solution may be right or wrong. It only reflects the general range or approach or even availability of ideas on a particular problem. At the specific execution of the solution stage, the problem is simply to fill in the minor details only. He then goes on to distinguish between meaningful errors and stupid errors. The former arise in the specific execution of the right idea and the latter ones arise when the grasp on the problem is either absent or too poor. He is then able to distinguish between organic solution and mechanical solution by the type of behaviour shown by the subjects during problem solving (In the final written form of the solution, this distinction is very difficult to maintain and Duncker is aware of this difficulty.) The organic solution is meaningful, less elegant, long and time-consuming whereas the mechanical solution is concise and follows a set pattern. Moreover, in the case of organic solution, one sees clearly the evidence for the analysis of the goal, analysis of the situation or conflict ("where is the ground of the trouble ?") and analysis of the material. For instance, Piaget's work on number shows the concept of mechanical solution in the case of children who compute accurately without even understanding the basic ideas.

3. Generally speaking, in the case of a successful solution, each response to the problem situation is in fact the reformulation of the problem developing organically. In prospect, it is the nature of another problem (Concretization of the goal) and in restrospect the nature of a partial solution to the problem. The formulation of the problem more productively, then, implies the emergence of one or more functional solutions where a specific statement or a series of specific statements leads to the final form of the solution or solutions).

4. *Role of cues and hints.* Cues and hints are only understood when they approach the "genealogical line already under-development" which is in conformity with Selz's General Law of Anticipation: "An operation succeeds the more quickly, the more the schematic anticipation of the solution approaches a complete anticipation." Cues and hints are not understood straightaway in the absence of any past schema approaching completeness (28).

5. Solutions learnt mechanically (*i.e.* without understanding) tend to be forgotten in the near future. Past experience then does not guarantee success because the very essential of the problem was not grasped then.

Productive thought and insight.

Gestalt psychology originated in the field of perception and the Gestalt laws developed in this area were shown to be applicable to learning, thinking and thought processes. Thinking was not a process reproducing knowledge or "thought was not an unaltered return of the previously learned experience" as hitherto considered. Even the recall would depend upon the prevailing conditions *i.e.* the very recall of the solution will be as good as the 'prevailing conditions allow'. It was thus that Wertheimer distinguished between structural and non-structural solutions. Duncker and Katona (another Gestalt psychologist) explalned productive thought in terms of synthetic insight and meaningful versus rote learning. Szekley went a step further by making an emphatic statement that the "very reorganization of knowledge is retrospective in character". With reference to school science teaching, this writer is of the opinion that the concept of productive thought is more basic than the concept of insight. In fact, the concept of insight is tied to the productive thought rather than the other way round.

Insight

This concept was first introduced in literature (animal psychology) by Kohler for describing the behaviour of chimpanzees when they successfully solved the problem. The suddenness of solution is implied when one talks of insight, its main distinguishing characteristics being click (Graham), aha experience (Hartman) and eureka (Ogden). The opponents of this new term attacked this concept fiercely and characterized it as 'mystic, mysterious, antiscientific and accidental'. According to them, this is so because it is not possible to anticipate this moment. Consequently, this term has itself needed a lot of explanation since its inception. All appear to agree that insight occurs when there is seeing of the new relationship, a restructuring of the field or an integration of experience. The factors favouring it are high intelligence, quality of the past experience and nature and content of the problematic situation.

If there is intelligible world, Duncker tried hard to distinguish between analytic insight (reproductive knowledge) and synthetic insight (productive knowledge). It is difficult to distinguish the solutions on the basis of these two subconcepts especially when 'understanding and inference may be present both in successful and unsuccessful attempts'. This difficulty further increases when Gestalt psychology does not evaluate productive thought (see Peel). This means that "the flash of insight is not an evidence of an unusual height to which intelligence has soared but an aptness of the solution suggested". It appears that the word 'insight' is tied to the various changes in the problem situation itself which impart the experience of insight to the problem solver. Van De Geer appears to have said the last word on it when he says that it formerly meant an inner experience, then a certain kind of behaviour and now a psychological principle.

Productive thought

Gestalt psychology does not evaluate solutions. One solution is as good as the other provided the demands of the problem are fully met. Productive thinking appears when a new problem situation (material, personal or social) is encountered by the problem solver. Productive thought is characterized by an element of forward thinking, by changing or restructuring the problem situation effectively in order to achieve the goal, by restructuring and restating the problem in the light of past explanation and contains ingredients of solving the problem through analogy, selection, coordination and structuring and restructuring (see Peel).

From above, it is clear that Gestalt psychology has implications for science teaching.

1. It visualizes an active role for the learner in his learning process—he is not a passive entity. This implication is naturally linked with self-study and self-education.

2. It discourages the acquisition of facts, concepts and principles without understanding.

3. It stresses divergent thinking (see Guilford) *i.e.* going far beyond the starting point in one's thinking by setting up all sorts of hypotheses (open hypotheses) and testing them either against the given data, the demands of the problems or setting up control experiments for excluding irrelevant variables. Thus new scientific concepts (insights) are gained through a series of acts of discovery, however small these may be (67).

4. Duncker has said the last word on teaching (see Peel)—'Proceed as organically as is feasible—even at the cost of brevity and elegance' (46, 47, 48, 49, 50 and 51).

(*d*) Phenomenological Theory

This theory of problem solving has been propounded by Van de Geer. It is a philosophical doctrine which dates back to the writings of Hussrel. From the psychological angle, it meant 'return to the immediate data of consciousness (direct experience) and the presence of meaningful structure in the world'. This descriptive form of phenomenology has influenced psychological thinking since then. Consequently, as a method, it makes implicit meanings explicit. This method is, therefore, free from prejudice and hasty or rapid conclusions *i.e.* direct experience is not an 'objective data' but it needs to be reflected upon which leads to the formation of insights, which are 'always open to elaboration of improvement'.

Different aspects of the situation may appear in perception but each of the aspects presents the situation as a whole. The various aspects differ only in the degree of transparency. It is thus possible to solve the problem by explication *i.e.* by reducing the non-transparency. Duncker's concept of restatement or reformulation of the problem is implied (covered) in the 'changes of aspect' character of the object. Van De Geer further adds that 'in a way, a thought process has coherence and consistency by its constant reference to the same underlying situation'.

This theory does not generate testable hypotheses. This is also true of some other notions like stages, steps and description of process which are found in the area of thinking and problem solving. The author then proposes a closed system (axiomatic model) in preference to the phenomenological approach which is an open field. In the axiomatic model, the problem solving "proceeds by a succession of choices from sets of possibilities" *i.e.* reduction of alternatives (48).

(*e*) Geneva School

More interested in epistemology than in psychology, Piaget has in fact contributed immensely to the whole field of psychology, *viz.* perception, reasoning, intelligence, dreams, moral development, number, space, time, play, thinking from early childhood to late adolescence, and other varied problem areas. By his admirers (favourable as well as unfavourable) he has been spoken of as:

> "discoverer of an unsuspected dimension of depth" (Isaac N.), "Master at developing the theoretical implications of his observations" (Hunt), "Zoologist by training, an epistemologist by vocation and logician by method" (Inhelder), "in continuation psychologist by accident" (Hyde), "Philosopher, logician and educator" (Flavell) and "a great speculator, careless and slipshod, having scant regard for statistics and standardized tests and procedures" etc.

Whether you prove or disprove Piaget, a dip in the Ganges of Piaget makes one sensitive to the strength and weakness in one's techniques and procedures (*vide* Hunt and Donaldson). After giving an initial shock to one who reads his work for the first time, Piaget intrigues and intrigues intensely his readers by uncovering facts through techniques which are not quite respectable enough in the usual sense of educational research. He does not uncover facts alone but builds single-handed a Piagetian realm in the field of child development outweighing all the works of other workers in the area. While evaluating Piaget's work, Flavell adds :

> Readings in Piaget "indelibly colour your perception of the field of child development, the kind of research problems, the kind of interpretations" provide "heightened intuitive intensity to penetrate deep into the phenomena...a gist living for a while in the Piagetian world can give one a feel for the grain of development which he did not have before he lived there......It is not just the sort of dimension one ordinarily looks to in evaluating a system. But perhaps it ought to be, since science is, in part, a matter of the end game of one mind influencing the beginning and middle games of others". (53).

It is not possible even to summarize the main contributions of this school to education because many of them are still conjectures and therefore need further experimental research. In England, Susan Issac, Peel, Lunzer, and Lovell etc. have interpreted Piaget from the educational point of view. In this section we will therefore confine ourselves to the recent work of Piaget and Inhelder namely "The Growth of Logical Thinking" with special reference to the "Adolescent Thinking'.

Basic Ideas

1. There is a constant interaction between the organism and its environment. Reflexive actions become interiorized in due course of time for which Piaget introduces two basic concepts namely assimilation and accommodation. These are two fundamental processes, the former refers to the absorption and integration of new experiences with the existing schemata and the latter refers to the modification of schemata

as a result of the new experiences. This is something like the concept of 'epignesis', a term borrowed from zoology where the 'function remains the same and the structure changes'. In this interaction, it is not possible to find the proportionate contribution either of environment or of organism to the total development. While surveying the evidence for and against the predetermined development, Hunt supports the view that "Analysis of Variance model in understanding this mutual interaction is meaningless."

2. As Piaget's theoretical frame of reference is deeply rooted in Epistemology, it will be appropriate to elucidate some of his ideas with the help of a Kelvin scale which is usually mentioned in physics books. This is an open-ended scale in which the lowest temperature (absolute zero which is theoretically possible), and the highest temperature are left unfixed. It is possible to visualize the same thing for this mutual interaction between the environment and the organism the beginning and end of which are difficult to fix. The beginning of this mutual interaction is difficult to fix first because of our inadequate knowledge on the beginning of life and its mysterious reproduction and, secondly, due to the historical growth of man itself since the pre-recorded history. To fix the other end of the scale is also difficult because of the very evolutionary nature of the knowledge itself with time dimension held in posterity. Regarding the former, the contributions from physics, chemistry, biology and mathematics are still clarifying the origin of life.

(*b*) This scale is independent of hereditary or individual experiences. It depends on both.

(*c*) On this open-ended scale, there are four stages covering the approximate periods of 0-2 years, 2-7 years, 7-11 years and 11-15 years called the sensorimotor development stage, pre-operational stage, concrete stage and the formal stage.

(*d*) The above-mentioned age-ranges can vary from culture to culture.

(*e*) The above-mentioned stages follow each other, *i.e.* the next stage incorporates the gains of the preceding stage.

(*f*) Individual differences at a particular stage are disregarded and similarly the specific differences arising due to the specific situations or experiences are disregarded but Piaget concerns himself with the sequence of development of child's thought.

(*g*) In continuation with (*f*), the majority of the normal children pass through these stages.

(*h*) Each stage has vertical and horizontal growth.

3. (*a*) Piaget describes cognitive developments in terms of stages which have already been mentioned. These stages as such do not clarify anything except logical steps obtained on a particular experiment or situation. Piaget investigates further the structure of these concepts with the help of symbolic logic. This analysis makes his whole work distinctive in character.

(*b*) With the help of his symbolic logic, Piaget distinguishes between the properties of the thinking processes at the concrete stage and the formal stage. Some of the distinctions are:

(*i*) All verbal thought is not formal. It may have in it a situation which is in fact concrete. So a formal problem may be solved concretely.

(*ii*) At the concrete stage, the subject is tied to the situation or the empirical data. He criticizes data and brings extraneous considerations into the problem situation. He understands the content of the problem but fails to appreciate the form of the argument.

(*iii*) At the formal stage, on the other hand, possibility dominates and reality becomes secondary. This is why at the concrete stage, the following problem is difficult. Shobha is fairer than Rukmani and Shobha is darker than *Shubh*, who is the darkest of the three? or a child at the concrete stage cannot appreciate this joke :—

Two friends decided to settle abroad. They could not decide the country in which to live. One favoured the U.S.A. and the other the U.S.S.R. As you know, it is difficult to write freely from U.S.S.R. detectives and censorships! So they hit upon a plan to deceive the authorities. The Russia-bound friend said : If I write to you a letter in blue ink praising Russia, you assume it is all wrong; if I write to you in red ink then the description stays all true. From Moscow, he wrote the following letter to his friend in U.S.A. in blue ink. "I trust that this letter finds you in the best of health and spirits. Russia is a wonderful country. The working class people rule the whole country. I have now an excellent job and there is a lot of money in it. I work twenty hours a week. I have a television set, a motor car and an air-conditioned flat. There is a lot to drink, eat and enjoy in the country. I now advise you to settle permanently in Russia. Lastly, I get everything in Russia that I need. The only thing, I could not get was red ink".

A child at the concrete stage is unable to appreciate this joke. After reading the letter, he persists in his concrete judgement about Russia as stated in the letter. This is, however, not true of the child who thinks formally. Moreover, it is at the formal stage only that the subject is able to obtain experimental proofs, find methods of discovery and develop insight into the nature of proof.

(*d*) Piaget formulates the properties of these thinking processes available both at the concrete stage and the formal stage in such a way as to include both *i.e.* their "mobile equilibrium and their ontogenetic formation."

(*e*) Combinativity, reversibility, associativity and identity etc.—available at the concrete stage—are shown to be generalizedat the formal stage. This explains the emergence of operational schemata like combinatorial, proportional and mechanical equilibria, etc. later on.

4. Piaget is not the first to recognize the importance of logic to test inferences based upon observations. He got this idea from the studies of Külpe and his students, at the Würzburg school whose studies on thought processes indicated the accessory role of images (not essential as associations would imply), possibility of reporting the intellectual feelings and attitudes and thought consisting of anticipatory schemata intention, rules and relationships. Apart from borrowing

models such as those of Klein and Bourbaki from modern mathematics, Piaget himself has developed one of his own called 'groupments' 'which are comparable to semi-lattices'. Inhelder has suggested the use of another weaker model which makes use of Boolean Algebra. Regarding the use of models, she says, "More than twenty years of research have shown that cognitive development approximates these models without attaining them completely."

Each stage takes time to form and attain equilibrium. Each stage thus formed and attained is incorporated into the succeeding stage. These stages follow each other in a fixed order for the majority of the normal pupils in which the specified age ranges can vary from culture to culture.

Educational implications

The educational implications of his work have not been worked in detail. In Piaget's scheme of ideas child is an active learner who works on the environment and transforms it, child learns maximally through self-activity and when he is in a group. In a group, it is so because the different members think differently, thus rectifying the mistaken individual viewpoints of each other. In good teaching, learning situations are presented to the students and it is the children who experiment, invent and discover the structures (scientific concepts and principles—see Bruner) for themselves. Otherwise the students learn these concepts at the verbal level only (23, 37, 38, 54 to 65).

(*f*) Acceleration of mental development

Vygotsky's view (1896-1934)

In a highly thought-provoking and original way, Vygotsky applies some of the tenets of dialectical materialism to the analysis of intellectual development. Whereas his principal theme is the study of relationship between thought and language as the title of the book shows, the educational implications of his ideas are immense. Piaget does not mention explicitly the educational implications of his work. Our impression is that whereas Piaget leaves us wondering at his mysterious concept of mutual interaction (between organism and environment), Vygotsky goes a step further with an explicit statement when he says, "Instruction precedes development" (66). He agrees with Piaget that complex form of thinking evolves from simpler forms of thinking but takes us one step ahead of Piaget when he analyses intellectual development as a function of instruction very explicitly. He did not live long enough (he died at the age of 38) to state the conclusions of his grand programme of inquiry in which the problems chosen and the techniques applied appear to be as searching and penetrating as the ones employed by Piaget. Bruner says, "Vygotsky is not stating a conclusion but a fruitful hypothesis—stating a program of inquiry which carries with it a vigorous and intelligent image of man." Some of his basic views relevant to science teaching are :

(*a*) Concepts do not exist in isolation like 'peas in a bag' in the child's mind. Contrary to Bruner's view, it is fruitless and meaningless to teach concepts and concepts alone directly. Like Piaget, he believes that succeeding stages incorporate into themselves the gains of the preceding stages. Concepts not only interact with each other but also each concept is a measure of generality. It has thus a place both in relation to other concepts and in the total system of concepts. It then becomes easy to understand that higher concepts throw light on the lower concepts *i.e.* concepts attained at the earlier age.

(*b*) The concept of structure in Gestalt psychology does not go far enough. It is too general to mean anything when he says : 'all cats are grey in the dusk of Gestalt psychology as in the earlier fogs of Universal associationism and concludes his critical survey by saying that "there cannot be substantial difference in approaches to the treatment of this problem when all psychological schools and trends continue to ignore that every thought is a generalization and that word and meaning cannot be studied in depth without any reference to development".

(*c*) He distinguishes between two types of concepts : everyday concepts and scientific concepts or spontaneous concepts and non spontaneous concepts which influence each other. Instruction is the main source of a child's scientific concepts which, in fact, corrects, informs and develops his initial knowledge. Instruction then does not remain an external agent but is seen to be integrated closely with development. Lastly, the scientific concepts develop in the opposite directions but still they are closely connected with each other.

Vygotsky, like Piaget, presents a developmental theory in understanding cognitive functions or processes. With the help of planned instruction, we should aim more at the 'ripening of such functions'. Piaget and Vygotsky with the concept of productive thought thrown in from Gestalt psychology present an integrated viewpoint to the teachers for teaching science effectively. (66).

Dienes Z.P's. view

It will not be out of place to mention in passing the work of Dienes on the concepts of abstraction and generalization. Particularly speaking, he has studied the attainment of specific mathematical concepts. Out of the many polarities in thinking, for the analytic-constructive is the most basic dimension in his scheme of ideas. The constructive thinker has an overall view of the goal and works intuitively towards it. He lets the details pass by and may attend to them later on. The analytic thinker progresses towards the goal (undefined in the beginning) consciously step by step as demanded by the 'logical requirements within the system'. Children at the concrete stage of development show constructive thought whereas children at the formal level (at adolescence) show analytic thinking. Children at the concrete stage of development may seemingly apply mathematical relationships successfully and thus manifest analytic behaviour when even their constructive thought is little developed for that mathematical relationship. In that case, they then manifest 'shadow actions without any logical significance' for they have not yet developed insight into the logical sequence of various events. Analytic activity is possible only when there has already been some worthwhile and significant constructive activity. Majority of children need a lot of constructive activities before they can develop analytic understanding. To illustrate his ideas further, he has not only constructed but also investigated concept development with the help of his mathematical apparatus (multibase arithmetic base and algebraic experiences material). On the basis of his work, he has formulated four principles of conceptual learning, these being the dynamic principle, the perceptual variability principle the mathematical variability principle and the constructivity principle. It will be an interesting exercise if whole of the school mathematics syllabus is classified at four levels according to these four principles in the form of mathematical situations to be gradually presented at various age levels. Accelerated mathematical thinking may then possibly result (68).

Accelerated thinking within certain elastic limits appears to be possible. It is not impossible to teach atomic theory and set theory etc. in the primary school by the new enthusiasts. They see too much in the so called explosion of knowledge but change of content or down-grading of content to the lower classes is a necessary but not a sufficient reform. Substantial and complete reform results only when relevant material drawn from the significant areas of human living as the subject of study itself is used to develop and improve thinking with the help of imaginative approaches based both upon the general objectives of education and the specific objectives (outcomes) of the particular branch of knowledge at various age levels. Suitable activities are then designed in the light of the preceding statement which further need to be empirically tested.

Problem at the focus of attention, reasonable freedom including flexible time tabling and responsive environment (outside classroom experiences, visit to the library, de-routinized laboratory work and the use of community resources and use of cheap materials etc.) are essential if the objective is to impart training in inquiry or even the scientific method. Children then do not accept the teachers' word straightaway. They question his statements and also test their own ideas under as many varied conditions as possible. In this triple process of concept formation, concept attainment and problem solving, incomplete hypotheses expand to complete hypotheses by appropriate rectifications where one strategy leads to another. Then the children donot tend to ignore the significant aspects of the problem. They attempt to resolve the ensuing conflicts in a problematic situation and may discover on their own new information and knowledge. This new knowledge is, then, not difficult to retain (see Von Restorff effect). Assimilation in contrast to accommodation and formation in contrast to information then take place. Cognitive structures are modified materially and are available for subsequent use. Then environment under natural conditions creates expectancies and violates them off and on and thus exerts an educative influence which is quite creative in character. This is a much strenuous job for the teacher to accomplish in comparison to the addition of a few isolated chunks of advanced knowledge in the school syllabus. Lastly, it is not possible to answer the problem whether accelerated development is possible or not because the research in this area is just coming up. This writer does not know of a single sequential educational plan empirically tested in the actual classroom conditions which informs us about the structures it produces at the primary stage and which are of subsequent use later on at the secondary stages and so on. This may in fact turn out to be a tremendous problem (See our Analysis of Problem Solving Processes in the next chapter). In the opinion of this author, a humble effort in this direction could be made by developing projects for the improvement of thinking in a few school subjects at some schools (67 to 69).

(*g*) Factor Analysis as a Method of Investigation

It is a highly mathematical technique aimed at analysing a series of tests in terms of minimum (Principal components method excluded) hypothesized factors and to clarify the relationships between them. There are many methods of factor analysis. Selection of a particular method is a matter of individual choice. Burt (1940), Wolfe (1940), Holzinger and Harman (1941), Thomson (1951), Cattel (1952), Guilford (1954), Frutcher (1954), and Vernon (1961) etc. have written a lot about these techniques.

By employing these techniques, it is [possible to find mathematically the structure of, say, reasoning ability. In

1938, Thurstone distinguished three types of reasoning abilities: namely, inductive reasoning, deductive reasoning, and restricted reasoning which have repeatedly appeared in other factorial studies. Guilford has further subdivided these into subabilities. Burt has identified three components of the reasoning ability as differentiated at adolescence, these being Induction (education of conceptual relations, perceptual relations and structural relations); Deduction (education of correlates, structural correlates and logical reasoning) and restrictive (general) reasoning (71).

Guilford and his associates have then attacked the phenomena of problem solving factorially. He defines problem as a situation for the problem solver when he has 'no adequate, previously learned and remembered device' to solve the problem situation. Steps in problem solving were determined by logical analysis. As all problems are not of the same type, they further considered problems with reference to content (figural, symbolic, semantic, behavioural); Operations needed to solve problems (preparation, analysis, production, verification and reapplication) and Products or Outcomes (units, classes relations, systems, transformations and implications). They found that 'problem solving itself is as vast as behaviour itself'. Their studies also indicated a key factor quite similar to strategies (Goodnow and Austin 1956) and Search Model (Duncker 1945) which determines the efficiency (effectiveness) of creative activity or thinking.' (23, 43*b*, 70, 71, 72 and 73).

Peel (1955) surveyed factorial studies in the teaching of science in England and concluded that there does not appear to be a group factor in science. On the other hand, there appears a 'complex of general intelligence, reasoning, spatial, number and other factors' (72). In his study: The 'definition and measurement by verbal methods of the ability to think critically,' Abou Hatab says :

1. "The hypothesized factors of critical thinking were not isolated as independent of other intellectual factors in a sample of 170 Grammar School Sixth Formers of the age of 17 years.

2. The main factors appeared, each includes various cognitive, productive and evaluative functions and requires different intellectual ability namely analytic thinking and intuitive thinking.

3. Critical thinking factors did not appear because these appeared to depend largely on general intelligence, reasoning and verbal ability" (70).

Lastly, Professor Hearnshaw, Dr. Hein and others have expressed their doubts on factor analysis. Prof. Zangwill states that intelligence testing is a "a technology whose theoretical foundations are distinctly insecure". Professor Vernon, however, is of the different opinion when he says that it is possible to develop a stable theory of intelligence on the evidence collected by the physiologists, geneticists, mental testers, factor analysts and the clinical psychologists etc. upon which the 'technological superstructure can be firmly based' (73). The practising science teachers will not be much interested in these types of theoretical controversies. On the other hand, they will be quite interested in knowing more about the problem solving personality and its development. A highly mathematical approach like the factor analysis can help us in substantiating mathematically the various hypotheses relating not only to the structure but also to the development of problem solving, creative thinking, critical thinking and original thinking set up by the researchers in this field.

(*h*) Information Processing

In our highly mechanical world, information is a basic commodity which flows through communication systems like telephone, automatic control systems, economic systems and even the human body and the brain. All the above-mentioned phenomena are included in the information theory which has been developed by the physicists and the communication engineers.

It has two branches which deal with the amount of information and the paths (including their stability and efficiency) taken by it in organized systems. It appears that the latter aspect is likely to prove more useful in the understanding of our nervous system and even social organizations. Thinking along this line has led to the development of high speed computers which are helpful both to the research scientists and psychologists in so many ways *e.g.* organization of data, reduction of data, and setting up hypotheses and their testing by 'modelling and simulation'. This approach to the study of problem (regarding thinking as information processing system and employing simulation) may yield quite promising results (Taylor). Possibly, we shall know about these results in the near future (74).

SECTION B

PROBLEM SOLVING

Little work has been done having direct bearing on this problem. The following pertinent studies, loosely classified, are reported which have proved helpful in defining, formulating and planning the experimental study of problem solving mentioned in the next chapter. It may be further mentioned that it is not possible to compare the results of one study with the results of other studies because each of them is different in its specific aims, methods, choice of experimental tasks and the type of sample chosen. All those studies fall under the following heads for the purpose of discussions in this section.

(*a*) Studies in concept formation.
(*b*) Studies in problem solving.
(*c*) Studies in the teaching of science.

Studies in concept formation

1. There is hardly any work done on the evolution of concepts in relation to their functional and quantitative aspects. There have, of course, been a few studies in the area of higher mental processes including a direct attack on the problem of generalization, "but still in every case, the studies have been largely introspective in methods, analytic in purpose, and qualitative in result". In this light, studies of Hull in the evolution of concepts are considered of first rate importance in their scientific approach to this problem. He investigated the problem with the help of suitably adapted (144) Chinese characters. A specially constructed device

presented these characters to the subjects. He concluded that formation of individual concepts is a gradual process in which trial and error plays an important part. Concept formation is facilitated when common elements in the situation are pointed out. A combination of formal and concrete (example) method is more efficient and functional than either of the methods used alone. There is, however, a distinct advantage when concrete method is employed in the evolution of concepts. This advantage is in the ability to define the concepts (75).

2. Smoke has investigated the role of hypothesis formation and its formation in the process of concept formation. He experimented with ten different concepts where each concept consisted of eight regular features and eight confusion features. The following two considerations were strictly applied in the choice of the above mentioned ten concepts namely "every condition essential to the concept must be violated once at least and each confusion figure must violate one and only one condition essential to the concept." The instructions varied from experiment to experiment but the general approach in its essentials remained the same. The responses of the subjects clearly showed the aspects of the situation which the subject had grasped or failed to grasp. He concluded that there is some form of grouping in concept formation. Secondly, in concept formation, hypotheses are set up or tested for their validity. Insightful behaviour may be present in some situations. Lastly, subjects have difficulty in expressing their concepts verbally when asked to do so when in fact they have developed these concepts (28 and 75).

3. With the help of 22 blocks varying in colour, shape, size and height etc., Haufmann and Kassanin have attempted to "distinguish between relevant aspects of the process and certain pseudo conceptual operations such as those involved in memorizing and recall". The subjects are asked to classify these blocks into four categories on the basis of some common characteristics. The experimenter helps the subjects in the classification but it is the subject's business to discover the basis of the four classifications. The subjects are asked to think aloud as they go along with this task. They were thus

able to distinguish three inter-related behaviours in the course of systematic conceptual thinking. These three behaviours were : categorical attitude, insight and the total consideration of the problem. It is only at the last stage that the subject considers the whole problem and attacks it on its merits. The nature of the task rather than the rules of the experiment determine his behaviour then (75).

4. J. S. Bruner, Goodnow and Austin have investigated the problem of 'Categorising and Conceptualizing' with the help of some thirty original experiments. They have attempted to explain "what happens when an intelligent human being seeks to sort his environment into significant classes of events so that he may end by treating discriminately different things as equivalents." Their novel approach 'refreshes and re-opens completely the great problems in the field', says Piaget.

Their investigation centres on the formation of concepts in a vast array of information and they have discussed the strategies which subjects actually use while forming concepts. Eighty-one special cards were constructed which varied in shape, colour and borders. A little practice on the meaning of 'conjunctive concepts' is given by actually showing a set of cards illustrating that concept. Then the actual experiment begins by asking the subject to find the underlying concept in the set of cards which are shown to him one by one. He is, of course, told whether the card is a positive or negative illustration of that concept. At the same time, he is expected to suggest one and only one hypothesis at a time. On the basis of these experiments, they have distinguished four distinct strategies by which a person may form the given concept, these strategies being the successive scanning, the conservative focussing and the focus gambling (76).

5. Investigation of concept formation among young infant children by Beard is one of the few factorial studies in which concept tests have been used. The chief aim of her study was "to see whether the various kinds of concept development as described by Piaget were self-contained or whether they corresponded, like the majority of intellectual tests, to a general factor, identifiable with general intelligence, and some

group factors in specialized fields". The other aim was to examine Piaget's concept of stages within the limited age range. Scores on the concept tests were correlated with calendar age, mental age, emotional, adjustment, socio-economic status, vocabulary and memory. Burt's group factor method indicated a general factor (mental age) and six fairly independent factors relating to physical phenomena, space and ability to reason with quantities. She confirms in principle Piaget's concept of stages but adds that his concept of stages needs to be modified a bit on account of individual experience and cultural influence (77).

Problem Solving

(1) This study by Buswell which is of observational and analytical character deals with the thought processes of a group of subjects (school children and college students) and attempts to describe individual patterns of thinking objectively if these at all exist. This study is neither experimental nor it involves any controlled groups. His main aim was to find out the extent to which the student structured their problems in terms of relevant, irrelevant and needed facts, estimated their answers first before solving the problems, processes involved in the process of generalization, ability to deal with symbol in contrast to a numerical figure and lastly to identify and describe the patterns of thinking if they really existed at all. His results indicated that subjects experience difficulty in expressing concepts verbally which they had in fact acquired (see Smoke) ; they do not estimate the answers before they start solving problems, failure to distinguish between the relevant and irrelevant aspects of the problem attracts all sorts of problem solving processes (see Vaidya) and lastly, 'variety rather than similarity in the sequence of thinking was the most striking and outstanding characteristics' even when common and uniform patterns of thinking were seen to emerge on total analysis of their responses (28 and 78).

(2) This study by Benjamin Burack deals with the nature and efficiency of methods of attack on reasoning problems involving induction, deduction and geometrical analysis carried on a highly select group of 25 psychology under-

graduates. Clear formulation of the problem, preliminary survey of all aspects of the presented material, analysis into major variables, locating the crucial aspects of the problem, application of the past experience, varied trails, control, elimination of the sources of error and visualization were the nine different methods of attack selected for this investigation. He concluded that it is very difficult to distinguish amongst different methods of attack (a problem may be in fact solved by a different method of attack). The nature and kind of problem itself determines the functional efficiency of a particular method of attack. Other methods of attack then become meaningless as they have then no relevance to the problem solving behaviour. This is not an unexpected finding when one examines the nine methods of attack a bit more closely *e.g.* visualization, control, varied trails, clear formulation of the problem and locating the crucial aspects of the problem which themselves are the functions of setting up and testing the various hypotheses attracted by the nature of the problem itself (79).

(3) Heidbreder has investigated problem solving in children and adults by exposing them to puzzle type problematic situations. She concluded that reactions and sensitivity to problems increased with age, a gradual change with age from a more subjective attitude to a more objective attitude and characteristic and individualistic reactions to the problems apart from the fact that "the general pattern f the solution became more general or definite but new rigidity set as the age increased"(80). Mumford has also investigated thinking processes as they occur when normal individuals are engaged in working out puzzles of various types. Her whole evidence pointed out that training, experience and practice influence thinking if thinking is regarded as a mental skill based upon innate capacity. School subjects can develop and promote problem solving if they are properly approached. Educative process is a vital experience in the life of an individual and needs to be handled with great care so as to develop self-confidence and persistence in the face of 'disappointments and threats of failure during problem solving' (81).

(4) Another experimental study of Problem Solving by Durkin which resembled Heidreder and Mumford's work in that it aimed to examine the effect of the nature of the problem solving process and the appropriateness of the concepts used to describe the behaviour involved. The subject was asked to talk aloud as he proceeded ahead with a well-organized series of two dimensional puzzle situations which could be photographed. At the end of the experiment, the subject was asked to retrace his whole solution from the beginning to the end. Any point of interest was discussed. The general conclusions of the study were :

(*i*) Problem solving behaviour in human adults is never at random in spite of the fact that they may not see the relevance of their moves as judged by the goal to be attained.

(*ii*) Three types of solutions were distinguished namely trial and error, sudden reorganisation and gradual analysis which could be termed as three distinct forms of thinking. There were, of course, certain transitional cases where such a distinction could not be made implying thereby the existence of a continuum.

(*iii*) Observation, recall, seeing relations, attention to the goal, manipulation and inference were the processes present in all the three forms of thinking (82).

(*iv*) This is a descriptive study of problem solving process by Bloom and Broader aimed to identify certain differences between successful and unsuccessful problem solvers while tackling problems relating to their academic subjects. Subjects were asked to think aloud and the verbatim records were made and analysed. The results were then discussed under the following four major heads :

(*a*) Understanding of the nature of the problem. This aspect is self-evident.

(*b*) Understanding the ideas contained in the problem. In this area, the major difference between the two above-mentioned groups lay not in the amount or fund of information needed to solve the problems (as expected) but was in their ability to make use of this information.

(*c*) General approach. Here, the successful problem solvers did not manifest restricted thought about the problem. They showed careful and systematic thinking and ability to follow the sequence of reasoning.

(*d*) Attitude towards the solution of a problem. In this area, the two groups differed in attitudes towards reasoning, confidence in the problem and the introduction of extraneous considerations into the problem situations (83 and 28).

6. The role of general or specific experience in problem solving is not agreed upon. Maier attempted to answer this question with the help of his well-known and famous construction problem. He tested the influence of experience in the solution of a new problem (not unusually complex) which could be subdivided into three separate and distinct experiences on which the solution of the new problem depended. The subjects involved were mostly Ph.D. students in different branches of knowledge (psychology, physics and chemistry etc.) in the Universities of Berlin and Michigan. These subjects were given as much time as they needed in solving this problem. Six different types of solutions were obtained. He concluded that the possession of necessary experience itself is not 'sufficient to solve certain problems'. He then introduced the concept of 'Direction' for explaining his results "which is the way the problem is attacked and depends upon the way the problem is seen to be". This concept of 'Direction' was later on attacked fiercely by Duncker who said that this new term was an unnecessary addition to the literature which in fact confused it and was represented or covered by his reformulation or restatement of the problem itself (84).

7. Employing the combined use of experimental, statistical and introspective procedures, Wheeler has investigated the development of reasoning in children. From her studies, she concluded that children possess logical reasoning at much earlier age than hitherto assumed by teachers and 'most of the elementary schemata necessary for valid reasoning are already within the capacity' of the seven-year-old children. It is only their subsequent development that helps children

attack the complex problems later on. This view is in conformity with Burt and Issac but contrary to Piaget and Inhelder (36).

It is at this point, Peel points out, that "there is more in common between Burt's and Piaget's view than is normally noticed". It is possible to accelerate the stages as suggested by Piaget and Inhelder by using right kind of experiences. Wheeler appears to ignore the very dependence of young children on 'concrete experience, expression and judgement'. There are of course exceptions and the choice of the theory rests on the explanation of these exceptions at various ages. Here, Piaget's view provides a more plausible account of the available evidence than the view put forward by Burt and Issac and confirmed by Wheeler in her studies (38).

Lastly, there still appears to be left some misunderstanding on the age at which formal reasoning begins. This age is found to be quite variable due to cultural differences and individual differences within the same culture. The most important question, still left unexamined, is whether each individual passes through these stages in succession as enunciated by Piaget and Inhelder or he is able to pick up the higher stage without having developed in him the preceding stage. This further points out to the possibility of jumps in Piaget's concept of stages. If this is found to be so, we have yet to know the relationship between the size of the jump (forward and backward) and the various conditions both within the individual and outside that make such jumps possible. Answer to this problem if obtained will be a great break-through in the education of children (28).

Teaching of Science

The growth and maintenance of our highly mechanical world depends upon the 'highest education of the highest intellectual'. It is really a poorer appreciation of this complex world if the psychological study of reasoning in science remains neglected. Even in U.S.A., Science Education Research is inadequate. In 1963, the editor of a new American journal in science teaching mentioned not only the features of the existing science research but also pointed out the nature of research yet to be done,"the design of most of the experiments remains more or less the same even over a period of thirty years, too many no significant difference studies appear to throw doubt both on the validity of measurement and hypotheses tested and too much time is spent on status studies on 'evaluating outgoing practice instead of functioning as beacon' (Dr. Smith)" (85).

The picture in fact is not as bleak as the above statement implies. There are a good number of studies, as the survey will show, in which authors have attacked the problem of science teaching from different standpoints. Examples are the studies of cause and effect relationship including the concept of causality as expounded by Piaget and the researches on the methods of teaching science incorporating the spirit of science.

G. Stanley Hall has studied the contents of children's minds and emphasized the importance of primary experience rather than bookish knowledge. He said that children acquired those concepts first which they encountered first in their immediate environment. Children thus develop right and wrong notions about common things. It is possible to eradicate their wrong notions at an early age. Teachers thus should converse with children about common things (87). Keen has studied children's reasoning and pointed out that young children have a 'weak urge for experimental verification' and hence care should be taken while introducing them to new experiences. Otherwise they develop illogical concepts which are difficult to correct. He further concluded, "that causal reasoning is not a generalised ability but depends upon the specific nature of the problem and a long array of specialized abilities, ability to use language being the most important one" (87).

Deutsche has investigated the nature and development of children's concept of causal reasoning—a phase of children's thinking in the light of work already done by Piaget and his co-workers. Problems with and without experiment were used. The two main results of this study were:

1. Reasoning develops gradually rather than stagewise.

2. Piaget's classification of children's reasoning into 17 types is not as useful as it is regarded in the study of children's reasoning. Moreover, school experience explains specific responses to the specific questions asked in this study which has its implication both for the direct and indirect teaching and training of children (87).

Oakes has made an extensive study (qualitative and descriptive) of children's explanations of natural phenomena. The specific aim of his study was to analyse the responses to direct questions consisting of a good number of verbal questions and simple experiments relating to various natural phenomena, classified into nineteen categories like common materials, rivers, simple experiments, machines and living things, etc. These problems were taken from Piaget, Issacs, Stern, Stevens etc., and a few others were added by the author himself. The responses were classified into workable categories like physical, internal, external and failure to explain etc. Subjects for this study were four groups of school children and one group of college teachers in non-science groups. The main findings of this study were :

1. The evidence does not confirm Piaget's concept of stages.

2. All age groups, regardless of mental ability and grade, gave all types of answers. The very working of the problem, the nature of the problem, past experience and vocabulary of the subject appeared to influence the pupil's response.

3. Adult groups did not follow any definite scheme or procedure while explaining unfamiliar phenomena. They made will guesses, lacked correct concepts and had little clear understanding of true causal factors.

4. As compared to the verbal questions, the simple experiments evoked a higher percentage of cause and effect relationships.

On the basis of his study, Oakes suggests a fruitful problem for investigation: 'A Careful Study of the Relation between Mental Ability and Type of Explanation of Natural

Phenomena' (86). Banks has studied the development of children's thought (11 plus to 13 plus) with the help of demonstration experiments which illustrated certain scientific principles. The subjects were low I.Q. pupils in a secondary modern school. His main aim was to find out the relationship, if any, between the kind of answer given and the age and I.Q. of the individual pupil. Deutsche's classification (materialistic and non-materialistic) was used. His results showed that these children can explain experiments which are performed before them intelligently. Secondly "age and science teaching had a greater effect on the ability to draw conclusions than did I.Q. but those with high I.Q. did better in the number of explanations in the higher categories" (88).

Navarra has investigated the conceptual development of his own son (very young and above average in innate ability) over a period of two years. This study is rich in detail and the observations are first hand. Moreover, the observations were based upon informal conversations. The most important findings of his study were :

1. The development is gradual and its most interesting and characteristic feature is the long period necessary for integration during which the child gathers together and interprets for himself the experience encountered in highly diverse situations, *e.g.* seeing water in its different forms and distinguishing it from steam or distinguishing steam from smoke.

2. In this development, there appeared the evidence of "gradual differentiation and development of expectancies, testing ideas, analysing experience, finding positive and negative instances and maintenance of an inquiring attitude" etc. Even the earlier insignificant details and concerns were seen to have initiated growth later on or constituted a progression of events in the total frame of reference (89).

With the help of Auto Instruction Device, Keisler and McNeil have shown [contrary to the view of Piaget (1929, 30), Deutsche (1937), and Oakes (1957)] that six or seven year old children can give scientific explanations for physical events and can even learn abstract scientific language (atomic theory). With practice, pupils would probably show—'more facile expression and more accurate use of scientific language in the solution of new problems'.

"Scientific thinking is largely a matter of good thinking habits", says Peel (72). It is in the light of this definition that we will survey some more studies on science teaching relating to laboratory work, scientific inquiry and problem solving. Implicitly, if not explicitly, all science teachers intend to develop good thinking habits among their pupils.

1. In 1925, Carpenter investigated the comparative effectiveness of laboratory and demonstration methods over 1,000 subjects and concluded that "pupils equally succeed well if success is measured by instruments which measure the same abilities as are measured by these tests, namely specific information and ability to think in terms of chemistry". (In 1958, Brandwein, Blackwood and Watson analysed the tests of Carpenter and commented that both the groups could succeed equally well independent of the above two methods on the basis of textbook knowledge alone) (41).

2. Horton (1928) attempted to probe further but confirmed the above-mentioned finding of Carpenter. His experimental groups were given : Individual laboratory work without direction, individual laboratory work with generalized direction, individual laboratory work with a manual of direction and demonstration by the teacher. His conclusion was "no reliable results appear in the testing by the ordinary written examination—neither by the regent nor by the school test". With the laboratory tests (non written), he found the following differences in ability *i.e.*, to set up and manipulate apparatus and to solve problems (or work on projects) in the labo ratory. In 1958, Frings and Hichar confirmed Horton's findings (41).

3. Atkin studied the role of accuracy of response, type of response (appeal to authority, use of observation, appeal to experimental and original explanation etc.) in formulating and suggesting tests for hypotheses in Elementary School Science Learning Experience. His main finding was that "pupils are more active, successful when they select and work on their problems" (41).

4. In an experimental study, Lahti ascertained the effectiveness of laboratory in developing student ability to use the scientific method to evaluate the effectiveness of the teaching methods and to design and construct laboratory experiments, and instruments. His evidence supported the following statement of Kruglak :

> There is hardly a better method of teaching scientific method than the one which places the student in the same position as the research scientist where he faces the same difficulties, commits the same mistakes, suffers the same accidents and explores the same blind alleys (91).

5. Extending over a period of about seven years, Kruglak has investigated some behaviour objectives for laboratory instruction, experimental outcomes of laboratory instruction, achievement of physics students with and without laboratory work, the measurement of laboratory achievement ; the effect of high school physics and college laboratory instruction on achievement in college physics and evaluating laboratory work by the use of objective tests etc. He confirmed the findings of Carpenter and Horton. Brandwein, Watson and Blackwood have emphasized the importance of laboratory work in their studies. Children then learn to work carefully, accurately, predict from first principles and select, design, search and improve laboratory equipment and techniques. At about the same time, Brown also made a similar type of investigation but without using any statistical niceties and concluded that "students who had physics laboratory work in high school were inept at naming or identifying the function of equipment which they were known to have handled in the high school" (92).

6. Recently, Muthulingam has also attempted to "assess the scientific thinking ability, attainment in science, attitude toward science and interest in the scientific field of boys and girls studying physical sciences in the fifth year of the secondary school in England and Ceylon and contribution of the factors in the schools, such as, the type of science course, the laboratory facilities and methods of teaching science, etc." A battery of tests was constructed to measure the various

aspects of scientific thinking : definition, problematic situation, reasoning, application of principles and ability to analyse and observe etc. Regarding application of principles, he says, "Results of the sub-test on the application of principles in England seem to be in favour of a method of teaching, emphasizing theory and restricted laboratory facilities." He further adds, "There is, however, evidence for better power of observation by the provision of good laboratory facilities and practical method of teaching (93).

7. Charen George has investigated the effect of open-ended experiments on the achievement of certain objectives of science teaching. Six M.C.A. (Manufacturing Chemist Association) experiments and six comparable traditional laboratory exercises were chosen for the experimental and the control group. The M.C.A. experiments involved certain elements of the scientific method like seeking solution to the problem, to make predictions and to set up apparatus and control experiments. Attempt was also made to test some attributes of critical thinking like ability to interpret data and to associate with the nature of proof etc. The study was carried over 268 students. His main conclusions were :

(*a*) Both M.C.A. experiments and traditional exercises in chemistry result in significant learning.

(*b*) M.C.A. experiments are a useful tool for the development of scientific attitudes, skills, motivation etc.

(*c*) There is no conclusive evidence that a laboratory approach has led to improved critical thinking in chemistry (85).

8. Butt has studied the degree to which children conceptualize from science experiences. He confronted 24 pupils from the fourth, fifth and sixth grades with science experiences in order to see concept development arising out of this new experience. Four other questions were also examined : relationship between concept development and chronological age, intelligence and attainment in science, influence of a given concept in the development of a different concept and recognition of a given concept in a new situation or experience. The

concepts under study related to displacement, inertia, action, reaction and depth pressure relationship. The experiments were done under three different conditions, namely experience phase, question phase and a manipulation phase. The findings of this study do not support the popular assertion that meaningful concepts will definitely emerge when a child is provided with proper experience or environment and the free opportunity to experience certain perceptions. In the opinion of this writer, it would have been better if Butt had considered the causes that contributed to this failure by analysing their wrong responses and interpreting them (5).

9. Szekely has attempted to investigate "knowledge as the starting point of independent thinking", by presenting the same problem in three different forms. Different subjects were used for three forms of the same problem. Consider the following problem.

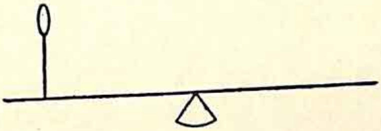


Fig. 6

(*a*) "The candle is lighted and the subject has to explain, why the lever falls down.

(*b*) The same arrangement. The subject is asked, what would happen if the candle were lighted".

(*c*) In this case, there is opportunity to find solution through free experimentation."

Szekely believed that knowledge can be investigated in its "function of end result, starting point and medium of learning and thinking". His main conclusion was that knowledge gets reorganized in the process of thinking which starts from the object of thought. Secondly, the three different forms of the situations (or presentation of the problem) differ only in the degree of difficulty of restructurization which again depends not only upon the piece of knowledge needed to solve the problem but also upon the consideration of the total situation.

In addition, Szekely investigated productive processes in learning and thinking and posed these problems. How is it that different individuals show vast differences in their ability to apply knowledge to unknown situations when they infact possess the same amount of knowlegde ? Does this depend upon the difference in innate capacity or the method of the teaching and learning ? Is it possible to increase the "productive applicability of the knowledge *i.e.* the capacity for creative thinking by the improvement of the methods of learning "?

Two methods of learning were compared, namely, the modern method and the traditional method. As learning materials, a few laws of mechanics served which were to be applied to a 'relatively different task, namely, the problem of two spheres'. The main findings of this study were :

(*a*) If judged by the frequency of successful solutions alone, the modern method is superior to the traditional method even when "endowment is taken into consideration". But Maltzman, Eisman and Brooks (1956) have failed to duplicate this finding. They did not find any significant difference amongst the three experimental groups. However, any one of the methods or even a combination of the methods produced more solutions than a control group with no training.

(*b*) Productive knowledge evoked in the process of problem solving and the verbal reproducibility of definitions are mutually exclusive of each other. This means that the rote memorization of definition or facts will not guarantee the solution of the problem.

(*c*) Improvement of the learning method improves comprehension of the learning material which fosters independent productive thinking later on (51).

10. Neal has attempted to ascertain specific procedures that aid children in developing the ability to use methods of scientific inquiry in grades (I to VI) in the laboratory school of Colorado. The author attempted to determine the elements of problem solving, to develop and select illustrative teaching

techniques which promote growth in the ability to use the methods of scientific inquiry, to judge the effectiveness of the various teaching techniques and lastly to observe and describe the kind of covert behaviour characterized as the method of scientific inquiry. Identifying and stating problems, selecting pertinent and adequate data, formulating and evaluating hypotheses and seeing relation were the various methods of scientific inquiry selected. He then concluded that children not only developed scientific interest, confidence and responsibility by the practice of scientific method but were also capable of developing abilities in practising the above mentioned elements of the scientific method (94).

11. Whellock has attempted to inquire "into how far scientific method is gained from Science Education". His subjects were sixth form pupils and military college students. After partialling out differences due to intelligence, he showed a significant relationship between the scores on method and attitude and the scientific background (95).

12. In this investigation of the thought processes of a group of fourteen year olds during the solving of a scientific problem, Kyle showed, "that abler pupils tend to progress by hind sight. They tend to jump to the end of certain phases and then to return to fill in the blanks...... A problem only becomes real for a person when he has some rudimentary foresight of a tentative solution......" He further showed that "a doing group went further towards a solution than a thinking group". This is so because a doing group can rectify its mistakes in the process of experimentation (96).

13. Mealings has investigated problem solving in science among secondary school children above 100 in number and of varying intellectual ability. Most of the problems were original ones and in fact seem to meet the requirements of complex human tasks as needed in such type of studies.

The general aim of his investigation was to understand from first principles the solving of scientific problems by the adolescent pupils in a normal school setting. More specifically, his aims were to investigate the relationship between the problem solving ability (at the formal level) and the mental age and to consider the influence of personal attributes on the problem solving ability. Sex differences were also considered. Two series of four experiments in each were administered among two groups of children in turn. A case study approach was employed and the responses were recorded verbatim, then arranged and analysed to see the course of thought on each problem. The main results of his study indicated that problem solving in science is more related to intelligence than to chronological age. (This is understandable). There appears to be a minimum mental age of 13 years before a child can reason formally about a problem and there is a time lag between the empirical solution and the formal solution. Taking an overall picture, Mealings says we should not expect children to solve abstract and theoretical problems in science until they reach a mental age of 16 plus. It is also possible, at this stage, to undertake topics requiring an understanding of metrical proportions, *i.e.* Boyle's Law, Ohm's Law and theoretical problems concerning moments and specific heat in physics and the laws of chemical combination in chemistry (98).

14. In a practical piece of research, Fleshner has emphasized the importance of children's every-day experience in teaching abstract concepts in physics. Researches of N.E. Weaver and E.N. Madden have advanced two conditions of success for problem solving, namely, the 'presence of corresponding knowledge' and the 'mastery of research operation'. For example the concept of weight involves weight for all bodies, earth's pull and force. Open-ended questions were posed to the children. Every child could answer at least a part of the problem. An interesting finding emerged that eighty per cent of the subjects were of the firm opinion that 'bodies which they had not measured had no weights'. Thus there is direct educational implication of the above : the definition (weight here) should not be taught and stressed too much in science teaching but on other other hand, it should stem from their floating ideas (living practice) when a given theme is introduced in the classroom (Goriachkin) (97).

16. Stendler is of the opinion that the superior intelligence does not imply "superior performance both in linguistic and

scientific fields". He emphasizes the importance of well-structured childhood experiences which facilitate learning later on. He explores the following hypothesis : "that certain kinds of childhood experiences structure an individual's perceptions of the physical world, that the percepts are stored as information cell assemblies in the cortex and that the neural reservoir facilitates the learning of concepts in the physical science". Then he discusses the nature of experiences that might contribute to the building of such a neural reservoir. He then suggests the use of teaching models that will help the elementary school pupils develop functional understanding and skills needed for the physical sciences (99).

Objective Tests

It is possible to develop objective tests to measure the various aspects of problem solving : ability to identify and define problem; ability to set up hypotheses and validate procedures through controlled experimentation, ability to collect data and make judgment, ability to examine and evaluate statements of others, newspaper advertisements and use of unwarranted generalizations etc. A step in this directionhas been taken by STEP (Sequential Tests of Educational Progress in U.S.A., particularly speaking)

17. There are definite trends in U.S.A. in approaching the whole concept of science teaching by developing its objectives from different angles like actual goals of science teaching, subject matter objectives, elements of scientific method, problem solving, interests, attitudes and laboratory skills. They then choose the sort of experiences that make or stress maximum development by making use of easily available community resources. In addition, professors in their respective subjects, research scientists, teacher trainers and science teachers in seminars and workshops think out certain concrete experiences that demonstrate highly mathematical concepts concretely. Thus advanced concepts are brought down to the children's level of comprehension. The Physical Science Study Committee, The Biological Sciences Curriculum, The Chemical Bond Project and Chemical Education Material Studies need special mention in this respect. There are many other

STATE INSTITUTE OF EDUCATION ... Bengal

projects which emphasize conceptual approach rather than descriptive approach to science teaching for obtaining maximum intellectual development. Some of these projects are:

1. Science Manpower Project, Teachers College, Columbia University.

2. Study of the use of History of Science Cases in Secondary School Science classes (University of Chicago).

3. University of California Elementary School Science Project.

4. Science Curriculum Improvement Study (University of California).

5. University of Illinois Elementary School Science Project.

6. Regional Conferences (Feasibility Study in Elementary and Junior High School Science of the American Association for the Advancement of Science).

There is similar concern expressed off and on in England. Science Masters Association and the Nuffield Science Foundation Project are doing similar type of work there. According to the organizers, reform in science teaching does not simply mean changing the syllabus or replacing one "rigidity by another". Reform must result in improved thinking, behaviour and action rather than in change of content (100).

Concluding Statement

It is now quite evident that problem solving theories are still in the stage of development. Consequently, there is not any clear cut theoretical framework in which one can see various researches on problem solving. We have yet to "determine the simple laws between dimensionalized independent variables and performance." This adds to the difficulty of evaluating studies relating to methods of teaching in favour of this or that method of teaching. Generalizations in that case have to be limited in the light of the aims and objectives of those studies undertaken.

There is another trend in science teaching which is gaining momentum more in U.S.A. than in England. This new thinking does not appear to be particularly based on psychological principles (in the opinion of this writer) but at the same time, it is empirically tested in classrooms. Its major feature is its main emphasis on the logical structure of the subject (itself) say physics, chemistry, biology etc. Elements of scientific methods are kept in focus all the time. The subject of a particular branch of science is chosen from the concept point of view in contrast to factual evidence. Highly mathematical abstract concepts are concretized before the very eyes of the pupils by developing new, novel and ingenious experiments and demonstrations. The teaching of abstract and advanced concepts is thus downgraded which is quite consistent with the 'Explosion of Knowledge' in our times. These efforts are quite laudable because they focus attention on the quality of learning experiences. The primary school children may learn a bit of atomic theory but it is unbelievable that they can think and act even like their counterparts at the higher secondary stage. The very ingenious demonstration of an abstract concept does not mean that it will be thoroughly grasped by the younger pupil on its first demonstration (See also Piaget's distinction between physical and mathematical experience). Results may prove disastrous if this logical approach and the various claims based on it are pushed too far in the ignorance of the laws underlying mental development. It is the knowledge of these laws (psychological approach) only which will help us in cutting and stitching scientific concepts (logical stuff) for maximum educational development with minimum of effort and cost in our country, thus getting the best out of these two presumably exclusive worlds (3*g*, 69 and 100).

CHAPTER 5

An Experimental Study

This is an experimental study of problem solving in science among certain groups of adolescent children. We have already discussed problem solving at length in the last chapter. After a discussion of the various viewpoints, we arrived at the following definition of problem solving. What takes place as task-oriented situation is presented to the problem solver and is aimed at to reach the goal.

Aims of this study

The main aims of this study were as follows:

1. To study the problem solving process on some selected problems in Physics and view the same with special reference to Gestalt and Piagetian Psychology.

2. To analyse the same in terms of basic processes needed to solve all these problems regardless of their type.

3. To interpret errors as they occur in solving these problems.

4. To study the problem solving process in relation to the following outside variables; intelligence, age, arithmetic reasoning, self-confidence, persistence, maladjustment, interest in things, emotional stability, co-operativeness, dominance, some immediate test reactions (understanding of the problem,

difficulty of the problem, interest in the problem, difficult words in the problem and newness of the problem).

5. To find out the characteristics of successful and unsuccessful problem solvers and

6. To study the role of hints and cues given on some of the problems. This in a way is reflected also in the manner of presentation of the problem itself.

Method of procedure

This study consisted of two parts. In the first part, a questionnaire approach was employed. A special letter was drafted which ran as follows :

I am interested in how people think when solving daily problems. You already know from daily experience that everybody thinks differently. You are going to be asked to think about some interesting problems in science. You will find that each problem can be solved in two, three or four different ways. You are allowed to think in as many different ways, as you can. In order to make your thinking easier for me to understand, you have been given some idea of how you are to tell me what your solution would be—either by completing diagrams, filling in statements and suggesting some quite different method etc. For this, sufficient space is provided and you can have more paper if you ask for it. This information about your thinking is very valuable to me and you should report almost all of it. It does not matter even if it looks silly. It is just possible that your approach may turn out to be right one. This you can do in the following manner :—

1. First read the problem as a whole. It will tell you what you are supposed to do.
2. As you go through the problem, many ideas will strike you. Please write down your ideas in the places provided. It is very likely that I may have missed some of your ways of thinking. For any different ones, you should use the spare space provided. Do not forget to number your idea.
3. If you find that the problem is difficult then do not get disheartened but do solve any part of the problem you can. I am sure you can do this.

4. Please be neat, clear, precise in your writings. You are free to reduce the amount of writing on any problem by summarizing a lot of attempts in any way you like.

Still further, every child was asked to give his personal post test reactions on each of the problems by answering a series of ten different questions which were :—

1. Did you find this problem difficult ?
2. Did this problem interest you ?
3. Have you done a problem of this type before ?
4. Did you try all possible methods to solve this problem ?
5. Did you solve a part of the problem ?
6. Were you muddled by this problem ?
7. How did you feel when you were solving the problem ?
8. What other ideas did you try in the problem that did not work ?
9. Do you want to put any question on this problem that may help you in its solution ?
10. Any other reaction that you want to tell me.

In the second part of the study, individual approach was employed where each subject was observed solving a series of nine different problems over a period of over two hours ; either a whole morning or afternoon. Instead of the post test reactions, here we took the immediate reaction to the problems on presentation which related to the difficulty of the problem, interest in the problem, newness of the problem and confidence in the problem. Incidentally, the role of difficult words, hints and cues was also studied.

Sample and subjects

This study was undertaken in two secondary schools in central London. In the first study, there were 60 fourth form boys of average intelligence from a secondary modern school. In the second study, eight pupils from a academic group, six from the engineering group, seven from the school certificate group and ten from the remedial group from the comprehensive school constituted the whole sample ($N=31$). Both the schools draw practically all their pupils from the same neighbourhood.

Tests used

11+test scores in English, arithmetic and intelligence, simplex group intelligence test, arithmetic reasoning test (Vernon) and some personality tests relating to persistence and self-confidence (Bhattacharya), maladjustment and interest in things (Harvey) and cooperation, dominance and emotional stability (Rehman) were used (101).

Problems used

The success of this study depended upon the quality of the problems chosen. The following considerations were kept in mind while selecting the nine different problems :—

(*a*) The problems should be new and novel but at the same time, they should demand thinking and continuous chain of reasoning.

(*b*) The problems should not be too bookish or be based upon any specialized knowledge etc.

(*c*) The problems should be simply worded so that pupils could follow what they were supposed to do. The problem as used are now described below :—

BEAKER PROBLEM

Micheal had four colourless chemical liquids in four beakers marked (1), (2), (3), (4). With the help of a dropper, he took part of the contents from these beakers in another beaker *B* to which he added a drop from the beaker *X* and obtained a red colour. In this process, he forgot how he had done it. Your problem is to suggest what he should do to be sure of it.

First method

He should take a few drops from the beaker (1) and put it into beaker *B* and then add a few drops from beaker *X* and see if the red colour is obtained. If not, he should try a second method.

Second method

Also so on.

REFRACTIVE INDEX PROBLEM

If you go swimming at the baths, you may have noticed that the swimming pool looks less deep than it actually is. This is called its "apparent depth". John, one day measured the real depths and the apparent depths of a number of swimming pools. He collected his results as under :—

	Real Depth	*Apparent Depth*
1.	8 feet	6 feet
2.	12 feet	9 feet
3.	20 feet	15 feet
4.	28 feet	21 feet
5.	100 feet	75 feet
6.	80 feet	? feet
7.	? feet	120 feet
8.	X feet	? feet
9.	?	Y feet

Write a statement which tells how you found the various answers.

TWO TEMPERATURE SCALE PROBLEM

In this problem, you are required to find the relationship between two temperature scales namely scale A and scale B. The following data are given for your consideration :—

	Scale A	*Scale B*
1.	100 degrees	373 degrees
2.	50 ,,	323 ,,
3.	20 ,,	293 ,,
4.	0 ,,	273 ,,
5.	Minus 20 ,,	253 ,,
6.	Minus 50 ,,	223 ,,
7.	120 ,,	? ,,
8.	? ,,	300 ,,
9.	? ,,	173 ,,
10.	X ,,	? ,,
11.	? ,,	Y ,,

Write a statement which tells how you found the various answers.

SPRING BALANCE PROBLEM

(A) In your science lesson, you got a spring balance that had no markings on it. Your science teacher urgently needed exactly 16 grams of salt for an experiment. He would give you :—

1. One one-gram weight.
2. One two-gram weight.
3. One three-gram weight.
4. One four-gram weight.
5. One five-gram weight.
6. One ten-gram weight and also containers of different sizes, each weighing one gram, are available.

How would you get exact 16 grams of salt ?
Write down all possible methods.

(B) Your teacher was interested in your ingenuity and asked if you could solve the same problem *i.e.*, getting 16 grams of salt by using not more than two of the above weights. Given also were the same spring balance and containers, a ruler and a pencil. Write down your method below.

FLASK PROBLEM

The illustration is of a flask that contains some sand. You are provided with the following apparatus :

1. Balance.
2. Suitable weights.
3. Water.

Your problem is to find the weight of water equal to the volume of sand in the flask. How will you do it ? You are allowed to take sand out of the flask if you so require.

First method

Second method

In this method you are given a graduated cylinder and anything else that you require.

Third method

In this method, the following data are given :—

1. Weight of the flask = 5 grams
2. Weight of the flask and sand = 8 grams
3. Weight of the flask full of sand =20 grams
4. Weight of the flask full of water =15 grams
5. Weight of sand alone filling the whole flask = ?
6. How many times is sand heavier than water ? = ?
7. Weight of sand in the flask = ?
8. Weight of an equal volume of water = ?

Fourth method

1. Weight of the flask = 5 grams
2. Weight of the flask and sand = 8 grams
3. Weight of the flask plus sand plus water =16 grams
4. Weight of flask full of water =15 grams
5. Weight of water above the sand = ?
6. Weight of water filling the whole flask = ?
7. Weight of water equal to the volume of the sand = ?

State how you found the last answer.

ELECTRICITY PROBLEM

You are given a battery, one bulb, some one-way and two-way switches and some connecting wires. Your problem is to find a circuit enabling you to switch on and switch off from two different places in a room. Complete as many of these diagrams as you find necessary to find the needed circuit and when you finish, write down a statement telling me how it works.

FISH PROBLEM

A fish tank is 52 inches deep. It is filled with water and a fish slipped into it. A boy looks down on the fish from the above surface and the fish appears to swim 24 inches below it. His friend puts his head under the tank and at the same time the fish appears to him to swim 12 inches away above the bottom. The problem is to find the thickness of the fish. You can ignore the thickness of the glass. It is given that

$$\frac{\text{Real depth}}{\text{Apparent depth}} = \frac{4}{3}$$

First method

1. Draw a diagram =
2. What is the real depth of the tank ? =
3. What is the apparent depth of the fish when seen from above ? =
4. What is the real depth of the fish when seen from above ? =
5. What is the apparent depth of the fish when seen from below ? =
6. What is the real depth of the fish when seen from below ? =
7. What is the combined real depth of the fish when seen from above as well as from below ? =
8. What is the real depth of the tank ? =
9. What is the thickness of the fish ? =

How did you find your last answer ?

Second method

1. What is the real depth of the tank ? =
2. What is the apparent depth of the tank ?=
3. What is the apparent depth of the fish from below ? =
4. What is the apparent depth of the fish when seen from below ? =
5. What is the combined apparent depth of the fish when seen from above as well as from below ? =
6. What is the apparent depth of the tank ?=
7. What is apparent thickness of the fish ? =
8. What is $\frac{\text{Apparent depth}}{\text{Real depth}}$ equal to ? =
9. What is the real thickness of the fish ? =

How did you find your last answer ?

LENS PROBLEM

We can know about a lens, whether convex or concave, by its focal length or its power. The focal length is measured in centimetres and the power in dioptres. The following data are provided for your consideration to discover the relationship between the focal length and the power of lens.

Focal length	*1 cm.*	*2 cm.*	*10 cm.*	*50 cm.*	*5 cm.*	*200 cm.*
Power	100 D	50 D	10 cm.	2 D	?	?

1. State your method.

(*b*) Now two lenses are combined together. Your problem is to find the relationship between the total power of the combined lenses and the individual powers of the two lenses.

The following data are given for your consideration :

Type of first lens	*Power of the first lens*	*Type of the second*	*Power of the lens*	*Total power of the combination*
1 Convex	20 D	Convex	10 D	30 D
2 Convex	40 D	Convex	20 D	60 D
3 Convex	50 D	Convex	5 D	55 D
4 Convex	40 D	Convex	? D	100 D
5 Convex	5 D	Concave	4 D	1 D
6 Convex	20 D	Concave	10 D	10 D
7 Convex	15 D	Concave	15 D	0 D
8 Convex	25 D	Concave	? D	15 D
9 Convex	?	Concave	50 D	100 D
10 Convex	15 D	Concave	10 D	? D
11 Convex	X D	Convex	Y D	? D

What is the relationship when two types of lenses are combined together, *i.e.*, between the total power of the combined lenses and its two individual powers.

(*c*) Two convex lenses of 5 D each are combined together. What will be the focal length of this combination ?

How did you do it ?

SIMPLE PENDULUM PROBLEM

I am showing you a simple pendulum. The number of swings this pendulum makes may depend upon

1. The length of the pendulum. You can measure its length.

2. The length of the swing sideways. You can change this amount of swing by starting the bob from different positions which can be marked on the floor.

3. Weight of the bob. You can weigh it.

4. The length of time for which this pendulum swings. You can read time from your watch.

Your problem is to set up experiments to show which of the above factors 1 to 4 are important in timing and which are unimportant. How will you get rid of the above factors 1 to 4 one by one and make your judgment on each one. I will write down the first step for you.

First Step

To get rid of the length of the pendulum, I would perform the following experiment.

Experiment 1

I would get a length of string with a ball on it. I will measure its length on a ruler. I will hang it up, pull the bob to one side and count the number of swings it makes in one minute. I will mark the point sideways at which I released the bob for swinging. I would now make the string longer, use the same bob, release the bob from the same marked point and again count the number of swings it makes in one minute. I would write down this second count as well. I would now shorten the length, use the same bob, release the bob from the same marked point, and record the number of swings it makes in one minute. Now I have to make a conclusion. I know all the three counts. If the three counts are different then I will say that different lengths give different number of swings in one minute. If the three counts are the same then I would say that length does not affect the number of swings in one minute. Thus I would know the effect of length on the number of swings of my pendulum.

Now proceed to get rid of the following:

(*a*) Weight of the bob

(*b*) Volume of the bob

(*c*) Length (amount) of the swing sideways.

Anything else that you require is supposed to be available.

Results of the Study

The results of the first part of the study indicated are:

(*a*) All the problems were new and novel for practically all the students. Most of them were interesting to all. Nobody had done the whole problem earlier.

(*b*) It is not true that the adolescent pupils do not make comments on the problem or, to put it more specifically, that they do not criticize the data. For example, in the beaker problem, Michael is advised to be more careful in future. There is evidence of a clear set of instructions for him. Extraneous considerations like painting the beakers, use of litmus papers and the chemical analysis of liquids are brought into the problem situation which are not in fact essential to the solution of the problem at hand (*vide* Piaget).

(*c*) There is a wide I.Q. Range (on 11+test) for both the successful and unsuccessful problem solver. This means that a low I.Q. pupil may solve a problem successfully where a high I.Q. pupil may fail on the same problem.

(*d*) There is a general tendency for adolescent pupils to appear to set-up hypotheses which they test against the data. A poor problem-solver appear to stick to one idea at a time and then ceases to think of alternative ideas.

(*e*) Schemas of Conservation (flask problem) and Poportion (refractive index problem, fish problem and lens problem) do not appear to be as well developed as we suppose them to be at 15+(See Piaget and Inhelder). The reason may be that the conservation of volume and conservation of weight interacted (See the flask problem). Most of the pupils failed to analyse this problem even when multiple questions were added in the problem to help them answer it.

(*f*) Generalization to algebraic symbols. Though most of the pupils were not familiar with the algebraic symbols, they showed that they were capable of doing so in some cases. It was interesting that one can see in their attempts the evidence of hypotheses that they had in fact considered, but had not mentioned specifically on the problem sheets *e.g.* changing feet into inches (see the refractive index problem). Secondly, when it comes to actual generalization, they concretize the symbol first. This again shows that the generalization to algebraic symbols comes out late in development as compared with the generalization on the quantitative data.

(*g*) Mathematical thinking. Generalization to the algebraic symbols in a way involves mathematical thinking. The last part of the lens problem (free from algebraic symbols) demanded mathematical thinking of an elementary type. 60% of the the pupils had formed the basic concept to solve this problem from the data supplied but only 33% of them were able to apply the concept successfully. This again shows that mathematical thinking takes time to develop and all of them cannot equally apply the basic concepts that they had formed.

(*h*) Factor analysis (Hotelling method). A correlation matrix was obtained for 17 different tests including nine different problems. The following were some of its main features.

1. The correlation cofficients between age and all other variables (with the possible exception of arithmetic) were low and insignificant at 5% level.

All problems were positively correlated with intelligence, arithmetic and English.

3. All problems were positively correlated with each other.

4. The correlation between self-confidence and maladjustment was negative ($r = -\cdot 31$) which is significant at 5% level.

5. The correlations between electric circuit problem on the one hand and the refractive index problem and the two temperature scale problems were quite low and were insignificant at 5% level. This is understandable because the former problem relates to mechanical experience and the other two problems deal with numbers only. This is also true when we consider the simple pendulum as well.

6. Correlations between arithmetic and the above-mentioned number problems are high and significant, the former at 1% level and the latter at 5% level. This argument is further strengthened if we consider the flask problem, lens problem and the fish problem as the 'number' problems only, the correlations being .51, .52 and .36 respectively which were significant at 1% level.

We were interested in analysing the structure of the problems if this could be done at all. Correlations and factor loadings were computed by the London University Computer Unit. This was, therefore, the justification of the Hotelling method used. Out of the 10 factor loading, only the first four were found to be significant for the purpose of our analysis. These first four factor loadings with the brief descriptions of the variables under study are shown on next page.

Factor Loadings

Variables	*Description*	I_0	II_0	III_0	IV_0
1. I.Q.	On 11+test	·709	·014	·475	—·113
2. Age	15+	·162	—·178	—·207	—·031
3. Arithmetic	11+test	·771	—·230	·060	—·103
4. English	11+test	·713	—·171	·358	—·072
5. Self-confidence	Personality tests	·257	—·458	·286	·450
6. Persistence	Do	·084	—·257	·416	·685
7. Maladjustment	Situation that worry and frighten people	·049	·660	·319	—·506
8. Interest in things	Like camping, Newspapers and puzzles etc.	·035	·181	·636	—·184
9. Flask problem	Schema of conservation and proportion	·776	·207	—·176	·365

10. Beaker problem	Possibly hypothesis setting up	·572	—·459	·121	—·055
11. Fish problem	Schema of proportion and conservation	·614	·188	—·164	—·088
12. Spring Balance	Categorization and proportion	·595	·267	—·383	—·090
13. Lens problems	Summation, proportion and application	·812	·208	·055	—·069
14. Electric circuit problem	Hypothesis formation	·417	·377	—·280	·271
15. Refractive index problem	Proportion	·561	—·365	·174	—·182
16. Two Temp. scale problem	Constant difference	·457	—·424	—·129	—·215
17. Simple pendulum problem	Setting up control experiment	·578	·499	—·141	—·105

It is easy to interpret factors I_0 and IV_0 straightaway without any rotation, the former being attainment and the latter being adjustment respectively. It is so because intelligence, English, arithmetic and all problems have high positive loadings on it whereas personality variables (self-confidence, persistence, maladjustment and interest in thing) have insignificant loadings on the same factor, *viz.*, I_0. The same argument applies to factor IV_0. Factor loading up to ·20 can be considered insignificant.

In order to interpret the table from the psychological point of view, there was still the necessity of rotating them. Two factors were rotated at a time *i.e.*, I_0 and II_0, I_0 and III_0, and I_0 and IV_0, II_0 and III_0, II_0 and IV_0 and III_0 and IV_0. Rotation between I_0 and IV_0 appeared to be the best one in the sense that it showed a good cluster. Out of the many rotations made, the following rotations were selected finally.

	Rotating factors	*Angle of rotation*	*Result factors*
(*i*)	I_0 and IV_0	6°	I_1 and IV_1
(*ii*)	I_1 and II_0	19°	I_2 and II_1
(*iii*)	I_2 and III_0	19°	I_3 and III_1

The values for these factors after rotation are shown in the table below. The serial order is the same as above.

Factor Loadings after rotation

S. No.	I_3	II_1	III_1	IV_1
1	·483	·246	·668	—·026
2	·200	—·115	—·129	—·011
3	·647	—·036	·320	—·009
4	·575	—·171	·576	·015
5	·123	—·368	·348	·477
6	—·213	·243	·366	·691
7	—·191	·666	·272	—·496
8	—·272	·167	·579	—·187
9	·654	·436	·042	·456
10	·615	—·247	·339	·015
11	·546	·387	·016	—·013
12	·571	·448	—·208	—·017
13	·537	·462	·277	·030
14	·334	·470	—·182	·312
15	·785	—·156	·052	—·112
16	·721	—·235	·111	—·157
17	·393	·682	·087	·174

Interpretation of factors

After rotation, the factors were then interpreted as follows :—

(*a*) Attainment factor (I_3). Intelligence, arithmetic, English and all the problems have positive as well as high loadings on this factor. Self-confidence, maladjustment, persistence, and interest in things have low and insignificant leadings on this factor. This factor can therefore be interpreted as an attainment factor.

(*b*) Practical factor (II_1), Flask problem, Spring balance problem, Lens problem, Electric circuit problem and Simple pendulum problem have high positive loadings on this factor. These problems do demand some sort of mechanical experience or they are in a way more of a practical nature. This is also supported by the fact that English, arithmetic and even intelligence have very low (and largely insignificant) loadings on this factor whereas personality variables have high loadings on this factor. This factor can therefore be interpreted as either mechanical experience or practical factor.

(*c*) Interest factor (III_1). Next to intelligence, Interest in things has the highest positive loading on this factor. All the problems mostly have insignificant loadings on this factor. This factor can therefore be interpreted as interest factor.

(*d*) Adjustment factor (IV_1) self-confidence, persistence and adjustment have high loadings on this factor. The rest of the variables *i.e.*, English arithmetic, intelligence and most of the problems have insignificant loadings on this factor. This factor can therefore be interpreted as adjustment factor.

Results from the main study

In the second part of the study, individual approach was employed (already mentioned). The results of this part are now mentioned below :

Analysis of Problem Solving Processes

In studying the solving of problems, we are more concerned with the processes of thought than with products of thought. our major interest, then, is the way the various answers to a series of test items in a particular problem are reached. As thinking processes are not open to direct observation and the various techniques available have their own advantages and disadvantages (*vide* Donaldson), one can only hope to know certain key points which map the route right from the presentation of the problem to the moment the problem is finally solved. Here, we discuss the problem solving processes as such by analysing all the problems used (electricity problem was dropped because it turned out to be very easy when presented concretely) in our study in terms of the thinking processes needed to solve all the problems regardless of their type for the entire sample. Moreover, we will also consider the problem solving process in relation to hints and cues (given) and difficult words contained in various problems.

Selection of problem solving processes

In our study, we defined the problem solving processes as follows :

(*a*) It is not simply addition, subtraction, multiplication or division process only.

(*b*) Within the context of the problem, its mastery is likely to lead to the solution of the problem.

(*c*) It excludes from its scope stating reasons for answers reached or stating method of procedure. All verbal statements were excluded. (See the problems)

(*d*) It is fundamental in character—each test item has been examined to determine whether it constitutes a problem solving process or not.

(*e*) and lastly, [the number of problem solving processes should not be unnecessarily too large.

Regardless of the type of problem chosen, it has been possible to group certain problem solving process which intuitively appeared to belong to each other. These groups are stated on next page.

Grouping	*Corresponding problems*	*Number of problem solving processes*
(*a*) Categorization	Spring balance problem	3
(*b*) Range	Beaker problem	4
(*c*) Conservation	Spring balance problem and Flask problem	2
(*d*) Summation	All problems involving Addition, subtraction	11
(*e*) Proportion	Multiplication and division	11
(*f*) Exclusion of variable	Simple pendulum expt.	4

These 35 problem solving processes are now mentioned below with reference to their attainment for the entire sample (N=31).

S.No.	*Problem solving process*	*Name of the problem*	*Example*	*Frequency*
1 & 2	Categorization	Sp. balance	Making 16 out of the given weights	31, 31
3.	Summation	Lens problem	40+?=100	31
4.	Categorization	Sp. balance	As 1 and 2	29
5.	Range	Beaker problem	Seeing one relationship	29
6.	Summation	Lens problem	As (3)	26
7.	Summation	Lens problem	As (3)	24
8.	Summation	Lens problem	As (3)	23

Problem solving process	*Name of the problem*	*Example*	*Frequency*
Summation	Two Temp. scale problem	120+?	18
Summation	Lens problem	XD, YD	18
Summation	Lens problem	Application of S. No. 10	18
Proportion	Refractive Index Problem	80 ?	18
Range	Beaker problem	Seeing the Second relationship	16
Exclusion of variables	Simple pendulum Problem	Taking into account fixed time	15
Conservation	Sp. balance Problem	Considering the weight of the balance	14

Range	Beaker problem	Seeing the third relationship	13
Conservation	Flask problem	Conservation of volume	13
Proportion	Lens problem	? 100=F.L. X.P.	13
Proportion	Flask problem	Third method	11
Proportion	Lens problem	? 100=F.L. X.P.	11
Range	Beaker Problem	Seeing the fourth relationship	10
Proportion	Fish Problem	Combined application of proportion and conservation	10
Summation	Two Temp. scale Problem	? 300	10

S. No.	*Problem solving process*	*Name of the problem*	*Example*	*Frequency*
24.	Summation	Two Temp. scale Problem	? 173	10
25.	Proportion	Refractive Index Problem	120 = ?	10
26 and 27.	Proportion	Lens problem	Proportion and its application	10, 10
28 and 29.	Summation	Two Temp. scale Problem	X=? Y= ?	9, 9
30, 31 and 32	Exclusion of variables	Simple pendulum Problem	Control expts.	7, 7, 7
33 and 34.	Proportion	Refractive Index Problem	X=?, ?=Y	6, 6
35.	Proportion	Spring balance Problem	Calibration	5

Here, a single drop of frequency is of major interest to us. It is so because either the particular problem solving process is present or absent in view of its being the maximum possible performance on it by the pupil. Of course, the extent to which a particular problem solving process is present is not shown but when all the problem solving processes are seen together, the aggregate usage of a process demonstrated by an individual may lead us to assess the degree to which the required concept or schema exists.

Now, the following findings emerge from the table. (Later on we will show that almost all the individuals share these responses):—

(*a*) The complex problem solving processes arise from simple problem solving processes. This shows out clearly why the calibration of a spring balance turns out to be the most difficult operation. It needs well-developed schema of categorization, summation, conservation and proportion. This is also true in the case of simple pendulum experiment where pupils are expected to set up control experiments to isolate and identify the relevant variables. The respective frequencies for the above two processes are 5 and 7 respectively.

(*b*) Generalizations involving algebraic symbols come out late in development.

(*c*) 11 problem solving processes relating to categorization, summation and range precede the schema of proportion. It means that the frequency falls from 31 to 18 before a problem solving process relating to the schema of proportion emerges.

(*d*) Conservation of volume (flask experiment) comes after taking into account the weight of the beaker in the spring balance problem, the corresponding frequencies being 14 and 13.

(*e*) Seeing the second relationship in the case of the beaker experiment, mastery of the fixed count or time in the simple pendulum problem and taking into account the weight of the beaker while weighing 16 grams of salt in the case of the spring balance problem are the problem solving processes which are quite allied to each other, the corresponding frequencies being 16, 15 and 14 respectively.

(*f*) Lastly, the second problem solving process relating to the schema of proportion emerges as soon as two other operations (seeing the third ,relationship in the case of the Beaker problem and the conservation of volume in the case of the Flask experiment) have been attained, the corresponding frequencies being 13, 13 and 12 respectively.

It is possible to interpret the whole table like this but the outstanding conclusion that emerges is that the individual differences in problem solving processes within a restricted age range (15 years) confirm and support Piaget in principle. This it true even when

(*a*) The problems chosen are different;

(*b*) No symbolic logic is employed for analysis;

(*c*) When the procedure of analysis employed is different *i.e.* our analysis is based on the presence or absence of a particular problem solving process when all the problems are analysed into 35 problem solving processes; and

(*d*) When intelligence and achievement vary sufficiently within a restricted age range.

Guttman Analysis

A proper criterion for testing the unidimensality of a scale or a test has been suggested by Guttman. According to him: "If a single, quantitative score is to represent, without ambiguity, the behaviour of an individual on a group of items, then we must require that it be possible, knowing the individuals score, to know his behaviour on each and every item in the group" (102). This is called the principle of reproducibility which implies that two or more persons cannot have the same score by attempting different parts of the same test if this criterion is perfectly satisfied.

The case of the development of thinking processes seemed to the writer to lend itself to Guttman processes of scaling the hypothesis involved would be that these thinking processes develop undimensionally and that in a group of individuals, incomplete development of the thinking processes may be observed through the medium of their problem solving processes. We have computed the coefficient of reproducibility in two different ways—by taking all the problem solving processes as such and secondly by grouping them on the principle that the problem solving processes that intuitively appeared to belong to each other should be grouped together: categorization, range conservation, summation, proportion and exclusion of variables (already referred). The two coefficients of reproducibility came out to be 81% and 96.2% (90% suggested by Guttman for practical purposes) which indirectly lent support to the stage concept of development is suggested by Piaget and Inhelder.

Lastly, this leads to the hypothesis that the development of schemata at a particular age constitutes a scale. This needs to be verified for all age ranges preferably by using the same problems which might be analysed into stages, schematas and thinking processes. The educational importance of such studies is immense because these studies will provide sufficient empirical information on the concept of assimilation and accommodation (as suggested by Piaget and Inhelder) with age as the third dimension.

Role of Hints and Cues

From the practical point of view, a teacher needs information about the quality and quantity of help needed by the pupils. A different kind of study is needed to supply this type of information. However, our experience in this respect has been as follows:

Hints and cues helped those who were very close to the solution of the problem. Characteristic responses were: "I was already considering this. I was getting the hang of it like this, I was already thinking like this". Sometimes the problem was solved even when a hint was being given. On the other hand, there were those who could not utilize the hint at all. For them, it may be repeated, reworded, reshown and even made concrete. The characteristic responses in this case were: "I do not see the point, you should have told me that the ruler is of some assistance, how can you find the thickness of the fish without the ruler, absolutely impossible, etc." They understood the hint but failed to apply it to the actual problem situation.

At the end of the analysis, it appeared to us that these hints themselves constituted subconcepts which need to be mastered before the problem can be solved. Where this mastery of subconcepts does not exist, it is possible to find some cases where the cue itself may be transposed to the problem situation itself. There we found ourselves very close to Duncker when he said :

"We can formulate the general proposition that a suggestion is the sooner understood or assimilated, the closer it approaches the genealogical line, already underdevelopment and within this line, nearer it is to the problem phase than in operation ; in short the more completely it is already anticipated. This law is a special case of a more general law which concerns not suggestions, in the narrow sense but the material of thinking in general."

Selz formulated as "a general law of anticipation" in the following manner : An operation succeeds the more quickly, the more the schematic anticipation of the solution approaches a complete investigation." It may be added here that studies of Reid and Marks (1951), Burnack and Moor (1956) and Maltzman, Eisman, Brooks and Smith (1956) also point out that all pupils cannot benefit equally from the hints and cues (43*b*, 46, 48, 50 and 51).

Some Statistical Relationships

We computed the correlations between problems and the other outside variables. The correlations with intelligence, arithmetic reasoning, understanding of the problem, confidence in the problem, difficulty of the problem and interest in the problem were .69, .51, .73, .71, −.60 and .44 respectively, the first five were found significant at 1 p.c. level and the last one at 5 p.c. level only. Other correlations with age ($r = -.13$), emotional stability ($r = +.16$), dominance ($r = -.022$), Co-operation (r = —·069), dominance (r = ·15), persistence (r = —·20), maladjustment (r = —·12) and interest in things (r = ·27) were found insignificant both at 5 p.c. and 1 p.c. levels.

Within a restricted age range, it is not an unexpected finding that problem solving processes correlate more with intellectual development than with age. In fact, its correlation with age is insignificant at 5 p.c. level.

It is also understandable that arithmetic reasoning is needed in solving problems. The correlation co-efficient being ·51 which is significant at 1 p.c. level. Test reactions (understanding of the problem, confidence in the problem and interest in the problem) correlate significantly with problem solving processes. These are immediate reactions to the presentation of the problems as a whole. They, therefore, play an important part in orienting the pupils to the problems as a whole. This finding is further reinforced when the correlation coefficient between problem solving processes and the difficulty level is negative (r = —.60) and is highly significant at 1 p.c. level. Further, the correlation with interest in things is positive (r = +.27) which is insignificant both at 5 p.c. and 1 p.c. levels. The role of this factor may be contributory rather than substantial in problem solving. Other correlations with emotional stability, dominance, co-operation, self-confidence, persistence were found quite low and insignificant, at 5 p.c. level. The reasons may be that our problems have been less task-oriented and consequently have not evoked these personality variables sufficiently well. This is only a guess or otherwise, our personality tests were only rough measures which were readily available as the supporting variables and possibly were not deep enough. Projective tests would have been ideal here.

Role of difficult words

It is difficult to study the role of difficult words in problem solving in our study especially when those words have intentionally been deleted from the problems (see the selection criteria). Nevertheless, a few words were still found difficult incidentally. The meaning of each such word was explained so that it did not interfere with their thinking.

Our experience, on the whole, showed that the poor problem solvers cannot hold the meaning of a difficult word for long. They, therefore, needed a bit more of explanation and repetition. These words made them a little tense and nervous but at the same time these difficult words did not appear to contribute to their poor performance. Not even one of them localized any difficult word when asked as the 'ground of conflict' or trouble. The successful problem solvers, on the other hand, accepted the meaning of the word once for all and then continued straightaway with the solving of the problem at hand.

Differences between successful and unsuccessful problem solvers.

Regardless of the groups (A, B, C or D), we chose eighteen pupils in all (about 58% of the whole sample) in two equal groups in such a way as to show substantial differences in problem solving processes. All the pupils in the score range of 4-10 and 25-35 were taken constituting two equal groups of unsuccessful and successful problem solvers. Then differences between means were tested on the following variables as shown in the table at page 147.

Variable	*Mean for the successful group*	*Mean for the unsuccessful group.*	σ_s	t	*Significance*
1. Problem solving Processes	30·78	7·11	1·35	20·5	Very highly significant
2. Arithmetic reasoning	48·9	22	3·07	8·4	S.F. at 1 p.c. level.
3. Understanding of the problem	12·4	5·3	1·1	6·5	do
4. Confidence in the problem	12	5.5	1·2		do
5. Interest in the problem	10·4	6	1·45	3	do
6. Difficulties of the problem	5·9	11·1	1·24	−4·2	do
7. Emotional stability	18·6	17·6	2·79	·34	Insignificant 5 p.c. level
8. Dominance	4·3	4·8	·94	·53	do
9. Co-operation	6·2	7·2	1·14	·87	do
10. Self-confidence	25·3	24·8	2·13	·23	do
11. Resistence	12·9	15·2	2·07	−1·1	do
12. Maladjustment	46·3	39·2	10·68	1·65	do

On the basis of our tests and within the context of our problems, successful problem solvers differed from the unsuccessful problem solvers with respect to arithmetic reasoning, understanding of the problem, confidence in the problem, felt difficulty of the problem and interest shown in the problem on presentation. On the other hand, no significant differences at the usual levels were found with all the personality variables relating to emotional stability, dominance, cooperation, self-confidence, persistence and maladjustment. Additional evidence on some of the unsuccessful problem solvers only further showed that the unsuccessful problem solvers were below average in mechanical knowledge, mathematical knowledge and spatial perception. Further, in the light of the class teacher's opinion, all unsuccessful problem solvers except one were highly distractable, showed poor concentration and were not interested in school work at all. On the other hand, the successful problem solvers came from the groups A and B. They were working for their O and A levels in physics, chemistry, mathematics and biology and consequently evinced keen interest in school work.

Summary

It may be pointed out that we have only investigated certain key points in the thinking processes of our pupils. Therefore, the processes of thinking leading to these key points have remained unexamined especially for those highly successful problem solvers who gave correct answers to these problems. A certain type of uniformity appears in their solutions which is, however, deceptive. Even within this narrow approach, we did not have the feel that even only two of the subjects had shown the same problem solving behaviour. These individual differences, characteristic to each, remain covered under the crust of the scoring key and selection of significant thought processes in relation to the specific aims of the problems under study. Post test reactions to the problems (at the pilot stage) show vast individual differences when such reactions were intentionally invited. More arbitrary errors and extraneous considerations will enter into the problem situation if the problems are chosen which invite wrong responses. Koffka has suggested the use of such problems for investigating thought processes (45).

Suggestions for further research

The investigation of thought processes is a piece of fundamental research which will explode our traditional concepts of educational norms either determined by heredity, experience (environment) or both. Cohen, Johnson, Vinacke, Duncan, Peel, Piaget, Inhelder and Watson etc., have pointed out the problems that still need to be answered in this area. Basically, it is a three-tier problem involving research in thought processes, method of teaching and subject matter objectives *i.e.*, selection of basic concepts. Naturally a very broad frame of reference is needed to answer these questions which can only be built if there were already a good number of specific studies in this area. The problems of the latter type are now mentioned below :

1. Preparation of consolidated information and its critical appraisal relating to the definition of problem, selection of problem, type of problem and the content aspect of problem at various age levels.

2. While discussing the responses of our pupils, we have felt some difficulty in distinguishing between concrete and formal thought. More definite information is needed for investigating the same problems over a wide age range.

3. Further studies are needed to verify whether the development of schemata constitute a Guttman scale at other age ranges as well.

4. Role of past experience in solving problems needs to be investigated.

5. Relationships between problem solving and personality variables (as many as possible) need yet to be mathematically determined and exactly established. A factorial approach could be helpful here. Further, it is possible to verify Piaget's concept of stages by including reference tests relating to human abilities like arithmetic reasoning, spatial visualization and mechanical reasoning etc.

It may, however, be added that solutions to the above mentioned problems are interlinked with each other.

Lastly, the whole field is full of problems, some real and others illusory. A future research worker should not feel inhibited in the light of past efforts or look upon faults in the problems as faults found in the rocks which are insuperable obstacles. He should strike with his hammer and penetrate deep with his drill. It is really about this that Plato spoke when he talked of "cutting at the joints" more than 2000 years ago !

CHAPTER 6

Implications for Science Teaching

> Mr. Polly went about the place considering the militant possibilities of pacific things—papers, copper sticks, garden implements, kitchen knives, garden nets, barbed wire, oars, cloth-lines, blankets, pewter pots, stockings and broken bottles—at the Potwell inn to face Uncle Jim.
>
> (From the History of Mr. Polly *by* H. G. Wells.)

Science, by its very nature, is free from dogmas and subjectivity. Hence science concepts and principles are subject to modification and improvement in the light of new evidence collected by the succeeding research workers. The fundamental problem, therefore, for the psychologist, is to investigate assumptions underlying human thought processes and the factors influencing them so as to provide guidance and information of the practical type to teachers to enable them to approach their work with confidence while teaching science to the children. More specifically, they need to know of psychological foundations for the intellectual structures required in the subject of science itself and their methods of teaching throughout the school course in order to effect a maximum of educational development. In other words, they need information about what is too difficult or too easy, what concepts they should aim at inculcating in their pupils of a given age. In science, especially they need to know how to motivate pupils by finding topics and problems of interest to them. Unfortunately, answer to these problems is not clear cut and is not likely to be given by any experimental study of this type. We, therefore, confine ourselves to those educational implications which only arise from our own study. The following points in this connection deserve special mention :

1. Immediate Reactions to the Problem

We have seen that undestanding of the problem, confidence shown in the problem, difficulty experienced and interest in the problem are positively and significantly correlated with the scores on problem solving processes. This finding immediately directs our attention to the selection of suitable problems for investigation. The problems selected should be neither too easy nor too difficult. If they are too easy, then they are not problems at all. If they are too difficult, they are not likely to be solved, and this could have many undesirable consequences in the lowering of both teacher and pupil motivations.

2. Distinction between relevant and irrelevant variables

At the research frontier, it is very difficult to distinguish between relevant and rrelevant variables. With this in mind, it is not possible (or even sensible) to introduce the ensuing educational anarchy which will result if problems whose solutions are not definitely known are presented to the pupils for investigation purposes. The workable proposition is that of analysing known problems in such a way as to develop what we can call 'the mastery of the research operation'. Some of its characteristics are : consideration of all possible variables (relevant and irrelevant), experimental attack of the problem first in contrast to the theoretical attack, suggestion of imaginative approaches, seeking testable hypotheses, full use of analogy, the critical examination of the demands and the given parts of the problem, guessing and tentative solutions etc. With the help of active experience and controlled experimentation, this will result in making the maximum use of existing knowledge or schema as compared with the acquisition and memory of facts alone.

3. Role of Hints and Cues

We have seen that hints and cues do not help all. These themselves appear to be subconcepts which need to be mastered first. This points to the need of graded problems that should be kept at hand so that the children are able to practise problem solving.

4. **Use of Programmed Techniques**

Whereas children could not structure our problems on their own, nevertheless, it is quite possible to lead them towards the structuring of these problems (see Flask Problem, Fish problem and Simple Pendulum problem). In this respect, use of programmed techniques may be quite helpful because it is possible to present the same problem in its varied forms.

5. Generalisation to algebraic symbols and mathematical thinking came out late in development. This is shown in our restricted age range. Thus advanced aspect of the subject matter needs to be tailored and stitched effectively and in fact it might be argued that highly abstract ideas should be left to those who are going to be future scientists and engineers. For the rest, what can be tackled with success, on the other hand, is the working out of those implications of science teaching which influence and modify significant spheres of human living.

6. In our study, we have seen that there is general interest in problem solving (significant at 5% level). Here is the opportunity and possibility to foster and develop this interest by choosing those problems which demand thinking, provide challenges, provoke thought and test concepts that have been already developed. In this respect, even the children's questions and problems themselves can constitute interesting educational material for teaching purposes. Moreover, children love to make effective and intelligent use of their evolving concepts. When given guidance, help and encouragement, they can be led to suggest hypotheses (right or wrong, this is a form of brain - storming) or draw conclusions by setting up control experiments, think out reasons and feel a sense of achievement.

7. The experience of Prof. Inhelder needs special mention at this point. She says that children can be made to discover things if they are presented with certain selected and planned problem situations which illustrate a certain physical principle

or law. It is then possible to introduce certain basic notions in physics and mathematics at much earlier age than hitherto considered. The only condition is that these notions "are divorced from their mathematical expression and studied through materials that the child can handle himself" (55). The analysis of these concrete situations (teaching situations) will go a long way towards seeing relationships by resolving the ensuing conflicts. It may be pointed out that the Geneva school also emphasizes the importance of inquiries made by groups which involve a social element (53 and 55).

In this connection, we present below a progressive science lesson for problem solving based upon our study. No elaborate apparatus is needed because our adolescent pupils are capable of reacting to the absent situations.

Read the Spring Balance problem as stated in the preceding chapter. Now consider the various responses that the author collected individually from the thirty-one pupils :

(*a*) Weight of the beaker does not matter much.

(*b*) Chop off one gram from 16 grams if you so desire.

(*c*) What has the weight of the beaker to do with 16 grams of salt ?

(*d*) Salt is then, I think, 15 grams or 14 grams.

(*e*) You can weigh the beaker afterwards.

(*f*) Why should ruler and pencil come into the picture ? They can stay where they are.

(*g*) I will hang ruler and pencil.

(*h*) Let me find the weight of the ruler and pencil. It is six grams, I suppose (only a guess).

(*i*) Take another spring balance.

(*j*) I will weigh upto 10 grams and leave the rest.

(*k*) Absolutely impossible with ruler and pencil.

On examining these responses, it becomes evident that our pupils answer this problem in the way they first understand it. These are their partial attempts at solving this problem which do not solve the problem successfully. This is so because their schematas relating to Categorisation, Summation, Range, Conservation, Proportion and the Exclusion of Variables are not as much developed as they ought to be and that is why there is failure on their part to solve the problem. More specifically, this means that a good science teacher ought to analyse a complex problem situation into its very simple or elementary reasoning processes for his students so that they master them successfully. If this is done, then he can show the irrelevance of those responses to his pupils during discussion. They are thus educated through these irrelevant responses. This will become quite apparent if a complex problem containing a continuous chain of reasoning is presented to the students who are capable of solving it both concretely and formally over a wide age range.

Let us now consider what happens when pupils grasp the essential of the problem.

(*a*) For the beaker. Use 17 grams. Here the pupil is not influenced at all by the demand of the problem *i.e.*, get 16 grams of salt. Weight of the beaker has to be taken into account.

(*b*) Use ruler as a lever and pencil as a wedge. Here, the pupil knows that weight into weight arms equals the product of power and power arm. This is an ingenious solution to the problem which the author had not considered as one of the alternatives. But the solution is correct because it does solve the problem.

(*c*) Extension is proportional to the weight stretching it. Mastery of this observation (process) immediately suggests the calibration of the spring balance and thus the ruler and the pencil are immediately utilised or their presence is immediately seen in the solution of the problem.

It should be noted that this part of the problem is neither a puzzle nor an advanced trick. The whole problem situation is open to direct observation. Further, the problem hardly demands more than the simple, straightforward and observation of this relationship – that increase in length of the spring is directly proportional to the stretching force.

A science teacher can easily select a few worthwhile significant problems for investigation by his pupils. He can then plot their thinking processes on a two or three point scale by arranging both the students and the mastery of the underlying thinking processes in the descending order. Immediately, he will know the incomplete thinking processes attained by his pupils. The following will be an ideal situation.

Analysis of Problem Solving Processes

Name of the Pupil	*Total Score*	*Problem Solving Processes*				
		1	2	3	4	5
Sood	5	P	P	P	P	P
Misra	4	P	P	P	P	—
Shubh	3	P	P	P	—	—
Kelkar	2	P	P	—	—	—
Saxsena	1	P	—	—	—	—
Vijaya	0	—	—	—	—	—

P stands for the problem solving process present in case of, say, Sood's thinking. Dash (—) means that it is absent. Pupils above share the same responses to the various problem solving processes regardless of their type. From the above table, it is very easy for the teacher to choose the appropriate learning situations so that his students master their incomplete concepts not only quickly but also effectively.

The above is a positive approach in the analysis of our pupils' thinking. Another approach would be to build a similar type of error table where the number of errors and the particular errors made could be shown. This is a bit more laborious. Over a couple of years, a teacher will be able to know the various errors that his students make at that age. He will also know the sort of achievement he should expect from the various categories of pupils—above average, average and below average. For this analysis, no knowledge of psychology is needed. On the other hand, this is an empirical approach to develop a progressive lesson in science based upon the analysis of the student's responses.

Secondly, it is also possible for a science teacher to invite questions and problems that arise in their student's mind. These problems can then be taken up for investigation. Thus it becomes possible for the science teacher to develop a worthwhile and significant programme in general science which has relevance for his students.

Thirdly, it is also possible for the science teacher to set a very general oral question to his class : what are the uses of electricity to us ? Pupils will talk of many applications which can be classified into Heating effects, Lighting effects, Chemical effects and Magnetic effects. They can be asked to draw the relevant diagrams which can be technically labelled as the lesson progresses. Then different methods of producing electricity can be asked and discussed. It is possible to demonstrate most of the ideas here. Lastly, Magnetic lines of force, Ohm's Law, house wiring, electromagnets, electric bell and even electric motor models can be studied and constructed. The author tried this approach and it works wonders with the young enthusiasts. It is really tough to cope with the students' enquiries but this sort of experience is worthwhile.

Fourthly, it is also possible to improve our pupils' keenness of observation without the help of any elaborate apparatus. Here the emphasis is on the quality of experience which broadens and deepens the conceptual approach to science teaching. It is quite possible to elucidate the molecular theory in a simple but an effective way even to the young adolescent pupils with the help of a few boiling tubes, a few beakers, a bunsen burner, a thermometer, some sugar and salt, a little ice and a stand with a clamp. They can be then instructed to perform a series of simple experiments and record their own observations relating to the rise of temperature every minute, temperature of the boiling water with salt and without salt, temperature of the steam just above the liquid surface, formation of saturated solutions and investigate every other possible variable. Points for discussion could easily be the three states of matter, saturated solution and the appraisal of molecular theory when applied to boiling and freezing. With a little more experimentation, it is possible to add more to the discussion—for example, sublimation by heating iodine crystals and condensation by showing droplets on well-polished metallic pot containing ice-cooled water. A lighted candle further elucidates the three states of matter *i.e.*, wax in this case. Lastly, a cold plate held over the lighted candle to collect "free carbon provides a good starting point for discussing physical and chemical change" (103).

The above are the approaches both in breadth and depth for developing functional scientific knowledge, skills, attitudes and interest etc. Here, the science teacher must set an example. He is in fact himself an example to his students the way he teaches science to them. He should critically examine himself what he emphasizes : the factual approach, the examination approach and the conceptual approach or a tool approach to science teaching.

Evaluation

This is not the proper place to attempt a rigid definition of evaluation. It will be only elucidated. You buy a table or chair from the shop, and take it home. Your wife then says that the table is not suitable in the dining room because it is either too low or too high or it does not fit in there as another would fit. Both of you then discuss whether it should be purchased at all even possibly for future use. Some value judgment (here utility) is involved. I teach mathematics to my class. Really speaking, I have worked very hard throughout the year. The inspector comes and sets a few questions to my class. My class, say, fares poorly on this test. A value judgment on my proficiency as a teacher is made here by the inspector. I also perforce then make a value judgment on the learning efficiency of my class. Take the case of my friend. He is a clever fellow and throughout the year, he has emphasized the examination stuff. All of his students pass at the end of the year. He is a successful teacher and may be given a medal on the basis of his examination results. It is highly probable that his students cannot think for themselves when they are given a few new, novel and thought-provoking problems. Suppose they then get confused and later on leave all the problems in disgust to their teacher. Should science teacher work for this type of recognition ? Take another case—a student has worked thoroughly well throughout the year. He fares badly in the annual examination. In the light of our own observation and opinion, the examination authority has failed to evaluate him properly.

A mechanical examination encourages mechanical teaching by the teachers and mechanical learning by the students. If tests demand more of rote memory, then we should be quite sure of producing good crammers. On the other hand, if the tests demand more of problem solving behaviour, we are sure to have individuals who can think for themselves effectively and independently as a result of our teaching.

There are many questions that need to be investigated before we can understand fully the concept of evaluation. With reference to science teaching, each of us has to ask the following questions :

(*a*) What do we aim at when various categories of children (above average, average and below average) come to us at school ?

(*b*) What should be the possible organisation within the school to make the best possible use of our limited resources in order to obtain maximum of educational development at minimum of cost with minimum of materials ?

(*c*) What could be the possible testing programme for our schools in order to base our educational policies and practices on objective data and what should be its main features ?

(*d*) What sort of intentions should be built in the school time table ?

(*e*) Should we assess the whole child or simply remain confined to the testing of a few definitions, descriptions, diagrams and numericals etc., the old way or the new way—"Are the methods of assessment varied enough to cover the whole range of a candidate's abilities and potentialities" in various school subjects ?

These are difficult questions but not at all impossible to answer and then act accordingly in direct proportion to one's strength of convictions. Only thus we can avoid one-sided thinking in evaluation : all statistics but no progress ! There is really no harm if we have our own opinion on some of the questions mentioned. The evidence is accumulating, that chidren at a particular age are not at all capable of thinking at a fixed level. (See Piaget, Vygotsky and Stendler). It is quite possible to change their norms of thinking because these are not at all static or fixed. By making a detailed inventory of thinking processes for our class, it is possible to choose suitable learning experiences and appropriate materials from as many diverse fields as possible and increase thereby the pressure of environmental learning in a manner like the concept of 'Museum of Defects' developed by an English psychologist before the second world war in Scotland in the area of spinning and weaving varied patterns where the existing role of heredity is shown to be of minimum importance so far as acquiring first class craftsmanship by the school leaver is concerned. Perhaps we should be ready for such similar shocks in our own trade in the near future.

Coming to the track, it is clear that the evaluation could be helpful to us in so many ways—determining an effective and self-growing educational administration and school organisation, effective realization of the educational objectives with the help of functional instructional materials and the development of suitable educational and vocational guidance programmes based upon ability, aptitude, age etc. Like electronics, feed back here determined strictly on the basis of objective data will make a big impact on our educational system.

Measurement data on student(s) have relevance only in relation to the objectives. Tools are constructed to measure instructional objectives or the outcome of instruction which we have kept in our view. Weightage to the objective can also be given which will differ from place to place and at the same place, from one class of pupils to another. So there is nothing objective about an objective. On the other hand, it is subjectively determined because it is the teacher's job to make a basic decision on each of the outcomes for his various categories of students—what scientific vocabulary, facts, concepts , skills, interest and appreciations, what problem solving situations to devise and choose, what learning experiences and activities to plan and choose for each group ? The problem does not end here, one can still subdivide these outcomes in concrete terms so that detailed analysis, work and guidance become possible. For example, problem solving behaviour can be broken as follows :—

(1) The pupil can analyse problems.

(2) He can interpret given data. He can make generalizations.

(3) He can apply these generalizations to unknown situations.

(4) He takes interest in solving advanced scientific problems.

(5) In times of difficulty, he sets up hypotheses, tests each of them against the given data and reaches the final solution. He attempts to obtain organic solution (see Wertheimer and Duncker) to the problem from the first fundamentals which at times may be quite different from the solution given in the textbook. This emphasizes discovery approach to science teaching. For all the above aspects of problem solving, situations have to be thought out and then tested empirically in the classrooms. Those situations that yield results can be retained and others discarded or postponed for attack at a later stage.

In this connection, a few suggestions of Dr. Hagen are quite helpful :

(*a*) State the objective in terms of pupil behaviour. One can detail a large number of behaviours around even one object.

(*b*) For the purpose of objectivity, consider only the overt behaviour. He also questions (functions) about things (natural phenomena) that he has observed is a good statement.

(*c*) In each objective, there should be one and only one process.

(*d*) Avoid value terms. Words such as 'at all times, in any situation, continuously, always and perfectly' should be avoided.

(*e*) Teaching and testing objectives should be more or less the same.

Here, this author is of the opinion that the teaching objectives should go far beyond the testing objectives. (See the chapter on the outcomes of Science Education) (104-*b*).

Nobody will be impressed by the declaration of high sounding objectives. A few objectives should be stated in realistic (practical) terms regardless of Dr. Bloom's terminology and attempts be made to realize them. Otherwise, the objectives will remain solid on paper and melt in action. More specifically, this means that the particular statement of an objective should be related to its corresponding learning experience which should be too rich and varied in character. The variables in this situation would be :

(*a*) Pupil—his C.A. and M.A.

(*b*) Teacher's objectives and the pupil's objectives.

(*c*) Learning experiences—includes scientific equipment as well.

(*d*) Evaluation.

It is becoming a fashion or a sign of up-to-dateness these days to criticize essay type examinations. Too much of this criticism is misplaced for essay type examinations do foster freedom of thought, expression, creativity, depth of knowledge and also widen scope of knowledge. If one cares, one can also diagnose incorrect interpretations and partially understood concepts. Pupils also develop superior study habits. They eliminate guessing and lastly, they are easy to prepare.

Further, it is possible to improve the essay type of questions that require short answers by giving hints to the examinees so that they know what they are supposed to do and consequently they easily organise their answers under the appropriate heads ; by avoiding vague vocabulary and phrases ; by giving suitable weightage both to the educational objectives and the content to be tested ; by making all questions compulsory as in the medical examinations so that the achievements can be mutually compared and lastly by balancing all the questions in difficulty etc. Moreover, some training in taking essay type examinations can also be given.

If any essay type question is made highly specific or structured, it tends to become a new type test item. In answering these test items, very little writing is involved : a word, a phrase, a tick and even underlining a particular word will do. These test items can also be based on given data, diagrams and experiments. It is also possible to test a complex chain of reasoning by new type test items say in science, mathematics and even languages etc. Their main advantages are : representative sampling of the content and abilities to be tested, useful for testing initial knowledge, diagnostic work, remedial work, individualized self-testing, objective scoring, easy to score, highly reliable and increased validity for some teaching objectives, eliminate bluffing and lastly they focus pupils' attention on specific facts and abilities. The main danger against which we should guard ourselves is that superficial learning should be reduced to the minimum possible. For us, the major challenge is that the quality of reasoning should be highly developed. We should rise above the controversy of objective and subjective scoring. We should look for quality or graded quality in our pupil's responses which inform us teachers about their conceptions and misconceptions, problem solving behaviour, critical thinking, creative thinking and original thinking. These responses can be arranged in the descending order of quality. The very concept of scoring then changes because one does not mark them simply right or wrong. An agreed suitable weightage is then given to every response.

Attainment of economy

If we take an overall view, thinking along these lines will result in—

(1) Balanced emphasis on first class objective of science education.

(2) Increment in stimulation, satisfaction, functional understanding the development of skills, attitudes, interests, appreciations and the gradual growth of scientific temper so inconspicuous in our teaching.

(3) Improved methods of teaching, concretization of abstract ideas through scientific equipment including A.V. aids and rich learning experiences as the whole science content will then become functional.

(4) The provision of rich and effective background preparation for diversified courses.

(5) Minimum stress on memory.

(6) The probable development of independent habit of thought and action, self-confidence and persistence.

Lastly, in this well thought-out programme empirically tested in the classroom by the teacher in his own surroundings, the children will be handling a process rather than the product of experience in a graded series of analysed and suitably selected science problems from the appropriate and significant areas of human living (104).

CHAPTER 7

Further Problems Ahead

In the preceding chapters, an attempt has been made to bring out in detail the outcomes of science education (functional understandings, skills, attitudes and appreciations etc.), the nature of thinking and problem solving (what thinking and problem solving are considered to be, logical steps in problem solving and illustration of problem solving), the various theoretical stand-points in science teaching (Maltzman's theory and programmed learning, Productive thought and insight from Gestalt psychology, Piaget and Inhelder's constructive theory of learning, views on the acceleration of mental development and information processing etc.) and we have then mentioned important researches on problem solving with special reference to science teaching including the experimental study of problem solving in science conducted by the author himself in London. Implications of teaching for problem solving in science have been then pointed out in their various aspects for the benefit of our science teachers. However, understanding problem solving in science and teaching for it is a little problem in comparison with other more significant and potential problems that require to be attacked first. These problems are now briefly mentioned below :

(*a*) We do not have clear cut commonly accepted as well as well-publicized statements of secondary education in terms of behavioural objectives relevant at the school level. School science is no exception in this respect. The statements so far made are too general and hence do not mean much when seen from the practical angle. If they are properly understood and attempts are made to translate them into action, these then tend to make impossible demands both on the science teacher and his laboratory. For example, there is not much difference in the statement of aims and objectives of teaching general science, physics, chemistry and biology at the higher secondary stage. Upto the middle school, there is complete chaos both in the definition and content of general science. A deceptively successful effort found an easier one, of course, appears to have been only in the direction of downgrading the content from the higher classes down to the junior classes of the primary school. For up-to-dateness in content, science teachers from all over the country are being gradually oriented in various programmes (P.S.S.C., B.S.C.S. etc.) which have little relevance for their daily work in the classroom. Lastly, the expenditure on science teaching is going up every year. A clear cut direction is needed here for avoiding waste and the danger of being over-ambitious.

(*b*) This brings us close to the controversy of content-*cum*-method that is going on in science education at the Regional Colleges of Education to-day. Making a student very strong in content (polishing pebbles) at school is a misnomer if we simply change the content for the sake of change only for all categories of pupils (above average, average and below average). Of course, explosion of knowledge affects and will continue to affect school science for many many years. 'A research paper of good quality is out of date on its first appearance to-day,' says Dr. D.S. Kothari. For this reason alone, we have to look for another alternative *i.e.*, teaching science as a process rather than as a product.

Teaching science as a process means that learning experiences contain and emphasize ingredients of description, classification, comparison, contrast, discrimination, setting up hypotheses, setting up control experiments, verification, prediction and training in the (scientific) method of acquiring new knowledge, and thereby to change and modify previous conclusions in the light of new evidence. Case studies well illustrated in the history of science can prove to be quite handy in this respect if they are not taught in isolation as is done to-day even at some places abroad.

From above, we can see that we do not have a clear concept of science both as a product and process at the school stage. Children at the school stage are not introduced to the big ideas of science drawn freely from the significant areas of human living. On the other hand, we teach physics, chemistry and biology—compartments of science. Children thus are not able to think scientifically in the different areas of science.

(*c*) Good science teaching does not always demand expensive laboratories. It is a dubious assumption that an expensive laboratory will itself automatically upgrade science teaching in our country. Cheap materials, out of classroom teaching, effective use of the community resources, improvised and home made apparatuses may in fact do the whole trick for us. It is quite possible to develop an effective course of school science based simply on demonstrations alone and then link these demonstrations to the theoretical ideas. Scientific ideas which are expensive to teach can wait. Development of scientific skills also can wait. It then becomes feasible in the light of the above statement to break the artificial distinction between classroom teaching (theory) and the (so called) laboratory work without suffering any significant loss of standards in science teaching. Solving the entire problem along the line suggested above will generate its own alternatives and we can opt for one of them (according to our need) which suits our pocket and the category of students we plan to teach.

(*d*) It is possible for the teacher to establish an intelligent dialogue with the members of his class without requiring any expensive equipment at all and thus to maintain a reflective atmosphere in the class. This can be done in so many ways : asking some questions (new type, essay type and even research type only for the few), by showing students their faulty answers and rectifying them as far as possible with their help, by providing opportunities to the students to test their ideas and finding the consequences of these ideas for themselves either through extra reading, extra experimentation at the science corner or through both, by developing outlines for the new subject matter through joint planning, making summaries and encouraging student writing on certain themes through class project or a series of group projects and even individual projects, improved experience in neat expression (written and oral) and added experience in comparison, contrast classification, description and discrimination. This will lead to the development of discussion technique as a reflective method of teaching based upon already classified and analysed data by the students.

It is always difficult to experiment with new ways of thinking and teaching—sometimes the results may be quite disastrous. In such situations, the science teacher needs sympathetic understanding both from his headmaster and the inspector—the one more conservative than the other in our country. Here the science teacher is likely to encounter many hurdles, some important of them being lack of communication from top to the bottom, rigid instructional tradition (conservative type), inability of the students to accept freedom and different methods of work, lack of self-direction and unavailability of expert advice on the teacher's part at some stage of his work, rigid syllabus, nationalized text-books, inelastic examination and the absence of reform in the air etc.

(*e*) There has been hardly any educational research in the area of science education worth the name to mention in our country even after independence. The reason for this is that research in science education hardly offers a rewarding career. With occasional tinkering here and there, science education in our country is still based upon the past tradition catering to scientific services in contrast to research and development. The following areas in science education need immediate attention :—

(1) Investigations into the aims and objectives including philosophy of science education.

(2) Development of a sequential plan of science education for different categories of pupils the Indian way right from the primary school onwards. The scope of this plan should be

quite comprehensive : integration of laboratory work and classroom instruction (already suggested), preparation of work books and preparation of cheap teaching aids and their effective use etc.

(3) Investigations into the methodology of teaching including training in scientific method under various conditions of teaching for different categories of students.

(4) Identification and development of scientific talent including the development of scientific interest and attitudes.

(5) Evaluation (and examination) in science.

(6) Adminstration and supervision of science education.

(7) Guidance and Counselling (not excluding occupational information) in science.

(8) Teacher training and the professional growth of science teachers.

It may be pointed out that the above-mentioned problems overlap each other. So the solutions to the above problems may be interlinked with each other. It is, therefore, suggested that the above problems may be formulated and reformulated more productively so as to yield results which contribute to the attainment of science teaching objectives in our country.

We have yet to find a body of science teachers who are capable of doing outstanding work and service in our science education and press them for active service. On finding them, we need to give them a clear mandate for the job to be done. Their work and their worth need to be recognised and success well-publicized. They need to be given comparatively better opportunities up the ladder on the basis of their outstanding work alone. Let us remember that in direct proportion to their convictions, it is the few science teachers alone who maintain and will maintain high standards—even international—in science teaching in this country. Even to those who really exist, we have not given any status at all in our science education. Their work is now being eclipsed by those University professors and training college lecturers who would hate to teach at school, if given the option and the same salary for the fear of becoming the proverbial school master. They will now up

STATE INSTITUTE OF EDUCATION Govt. of West Bengal

grade—our science teaching by prescribing something (untried and unexamined) wonderful. They in fact intend to play only the role of advisers—a role not usually difficult to play. To add to this, there is another problem. With the establishment of higher secondary schools, we have injected a good number of postgraduate teachers (M.Sc. B.Ts/M.Eds.) in some states. The general experience there is that they are not at all interested both academically and professionally in the improvement of school science. So far they have not at all contributed a bit—but who asked them ? All bright ideas but no substantial progress !

It is really our good luck that we are facing comparatively fewer problems than we should in the light of the confusion, created by the unsolved problems mentioned above. If this state of affairs continues for a decade or so, we will then really succeed in making a mess of the whole school science... like the five blind people who went to see the elephant abroad and came back home to reconstruct its image unsuccessfully and in their own way. Serious thinking in science education, which means teaching science effectively on the cheap, is yet to begin in our country. It is only after this first step that we will be able to build an Indian Tradition of Science Teaching in our country based upon the constructive imagination and collective efforts of a few outstanding science teachers and their followers over a large number of years. Without this vision, we will be lucky if we do not fail miserably in the next decade.

References

1. Thought, September 1964.
2. This article under the name of the author appeared in Education Forum, Alumni Association C.I.E., Delhi, April 1965.
3. This article under the name of the author appeared in Nav Prayan, Regional College of Education, Ajmer April 1966. Further references on this article are :
    - (*a*) Science in Secondary Schools, Ministry of Education pamphlet No. 38, London H.M.S.O.
    - (*b*) The Teaching of Science in Secondary Schools compiled by a Joint Committee of the Incorporated Association. Revised Edition, John Murray, London, 1958.
    - (*c*) Policy Statement in Science Education issued by the Science Masters' Association and the Association of Women Science Teachers published by John Murray, London, 1961.
    - (*d*) Progress Report. Nuffield Foundation Science Teaching Project, Nuffield Lodge, Regents' Park, London, October 1963.
    - (*e*) Jacobson W.J., Lessons from Britain, paper read at the Eastern Regional Meeting of the Association for the Education of teachers in science at the Teachers College, Columbia, Columbia University on October 27, 1960. Also reported in Science Education of April, 1961.

(*f*) Ellis Amabel Williams, The Lesson Unlearned, Guardian, February 25, 1964.

(*g*) School Science Teaching, Report of an Expert Conference held at the University of Ceylon Peradeniya 1963, H.M.S.O., London, 1964.

(*h*) Half Our Future, A report of the Central Advisory Council for Education (England), H.M.S.O. London, 1963.

(*i*) Robbins, Higher Education, H.M.S.O., 1963.

(*j*) Plowden Committee report now. There have been occasional press reports on the Primary Education from time to time.

(*k*) Ashby Eric, Technology and The Academics, An Essay on Universities and The Scientific Revolution, MacMillan & Co. Ltd., 1959.

4. Science Teaching in India is summarized from the following sources :

(*a*) The Condensed editions of the First, Second and Third Five-Year Plans, Planning Commission, Delhi.

(*b*) Central Advisory Board of Education, Silver Jubilee Souvenir, Ministry of Education, Government of India, 1960.

(*c*) Report of the Secondary Education Commission 1953.

(*d*) World Survey of Education IV Higher Education Unesco, 1960.

(*e*) Shrimali K.L., Education in Changing India, Asia Publishing House, Bombay and Calcutta etc. 1965.

(*f*) Sharma D.N. and Sharma R.C. ; Teaching of Science Dhanpat Rai & Sons., Jullundur and Delhi.

(*g*) Rawat D.S., Vigyan Shikshan (Teaching of Science), Vinod Pushtak Mandir, Agra 1966.

(*h*) Report of the India Parliamentary Scientific Committee N.C.E.R.T., New Delhi.

(*i*) Position of Science Teaching In Indian Schools—A Factual Report, N.C.E.R.T., New Delhi.

(*j*) Report on Science Laboratories and Equipment in High/Higher Secondary Schools published by the Committee on Plan Project, Planning Commission, 1962.

(*k*) Report on Science Education in Secondary Schools Committee on Plan Projects, Government of India, New Delhi, November 1964.

(*l*) Science and Mathematics Education In Schools in India, Report of Unesco Planning Mission of Experts N.C.E.R.T., New Delhi., 1964.

(*m*) Wanchoo V.N., Mathematics and Science Education in Indian Schools, All India Science Teachers Association, Delhi, 1965.

(*n*) Educational Forum, Alumni Association, C.I.E. Delhi.

(*o*) Joshi A.C., Science Education in the Fourth Plan, Naya Shikshak, Science Education Special Number, the quarterly journal of the Department of Education, Bikaner Rajasthan January, 1966.

(*p*) Constitution and Bye-Laws. All India Science Teachers' Association, Delhi.

(*q*) The Science Club Movement in India and the programme of the Department of Science Education available from the Department of Science Education, N.C.E.R.T., Delhi.

(*r*) Goldsmith Maurice, Science in India, Need for a new temper. The Times of India September 17, 1966.

(*s*) Kothari Commission's Report (Summary) 1966.

(*t*) Rawat P. L., History of Indian Education, Ram Prasad and Sons, Agra.

(*u*) Proceedings of the All India Seminar on the Teaching of Science in Secondary Schools published by the All India Council for Secondary Education, Ministry of Education, Government of India, New Delhi.

(*v*) Quoted from Participant Journal November 1966, Indian—American Technical Co-operation Programme.

CHAPTER II

OUT COMES OF SCIENCE EDUCATION

5. Thomas Jean and Majault, Primary and Secondary Education, Modern Trends and Common Problems Education in Europe, Council for Cultural Co-operation of the Council of Europe, Strasburg, 1963.
6. The Observer, Education Our Untapped Wealth, August 13, 1961.
7. Policy Statement in Science Education issued by the Science Masters Association and the Association of Women Science Teachers, John Murray, London, 1961.
8. (*a*) The Education Forum of January 1961 published by Kappa Delta Pi, an Hon. Society in Education, Technology and Social change.
    (*b*) Unesco Chronicle, UNESCO House Paris, Vol. IV, No. 12, December 1958 pp. 400-404. Discussion of eight eminent scientists on Man, Scientific and Technological Progress reported by Lionnais Taniale.
    (*c*) Beveridge W.I.B., The Art of Scientific Investigation, Heinemann, 1957.
9. Goodall M.C., The Changing Structure of Science, New Scientist, October 31, 1963.
10. (*a*) Nokes, M.C., Science in Education, Macdonald, London, 1949.
    (*b*) KARUNARATNE, W.A.E., Scientific Research, The Colombo Apathecaries Co. Ltd., Colombo, Ceylon.
    (*c*) Nagel, Ernest, The Structure of Science (Problems in the logic of scientific explanation), Harcourt, Bruce and World, Inc., New York, & Burlingame, 1960.
    (*d*) Weddington, H.C., The Scientific Attitude, Revised Edition, Penguin Books.
    (*e*) Laboratories in the Classroom, New Horizons in Science Education, Science Materials Centre, New York, An affiliate of the library of Science, 1960.

(*f*) Caldine, H., The Power and Limits of Science, A Philosophical Study, Chapman and Hall, 37, Essex Road, W.C. 2, 1949.

(*g*) Karl Pearson, The Grammar of Science, J.M. Dent, and Sons Ltd., 1937.

(*h*) Science in Primary Schools, Ministry of Education Pamphlet No. 42, H.M.S.O., 1961.

(*i*) Scientific Interests in The Primary School, National Froebel Foundation, 2 Manchester Square, London, W.1, 1958.

(*j*) Science in The Primary School (Science Teachers Sub Committee) published by John Murray, Albemarle St. W. 1, 1958.

(*k*) Beck, S.D., The Simplicity of Science, Lutterworth Works, London, 1960.

(*l*) Conant, J.B., On Understanding Science, a Historical approach, New Haven Yale University Press, 1947, (Terry lectures).

(*m*) Harris, R.W., Science, Mind and Method, Basil Blackwell, Oxford, 1960.

(*n*) The Place of Science in Primary Education, The British Association for The Advancement of Science, 3 Sanctuary Buildings, Great Smith Street, London, S.W. 1.

(*o*) Progress Report, Nuffield Foundation Science Teaching Project, October 1963, The Nuffield Foundation, Nuffield Lodge, Regent's Park N.W. 1.

(*p*) Calder Ritchie, Profile of Science, George Allen and Unwin Ltd., London, 1953.

11. Griggs Cedric, Science in the Primary School, Curriculum Studies No. 2, The School Master Publishing Co. Ltd., Hamilton House, Hasting St., London W.C. 1.

12. (*a*) Heiss, O'bourn and Hoffman, Modern Science Teaching, The Macmillan Company, New York, 1951.

(*b*) Lord Hailsham, Scientific Education in a scientific age, Policy for school science, O.E.E.C., Paris, September 1961.

(*c*) Marson Irvine, Problems in The National Teaching of Science, The Alexander Pedler Lecture, 1931, British Science Guild (93).

13. Lauwery, J.A., Baker F.A., Education & Biology, Sands and Company, London, 1934.

14. (*a*) Scheckles M., Building Children's Science Concepts, Teachers College, Columbia N.Y., 1950.

(*b*) Martin Edgar, The Major Principles of the Biological Sciences of Importance for General Education, Circular 308, U.S. Department of Health Education & Welfare, June, 1956.

(*c*) Wise Harold, A Determination of the Relative Importance of Principles of Physical Science for General Education in Science Education, December, 1941, January 1942, February 1943 and Sep./Oct. 1943, Also see Science Education, 1944, pp. 268-269.

(*d*) Vaidya N., A Factual Analysis of Science Concepts as judged by the General Science Text Books for primary classes in the States of Punjab, Himachal Pradesh, Jammu & Kashmir, Delhi and Rajasthan and a critical evaluation of the same in terms of the desirable criteria of the concepts as judged by some teachers, M. Ed. Thesis, C.I.E. Delhi 1958-59. For Summary, see C.I.E.M.Ed., Studies for the year 1958-59.

(*e*) Outcomes of Education for the first eight years of school published by the Vidya Bhavan Society and distributed by the Extension Services Department Teachers Training College Vidya Bhavan, Udaipur. It contains a chapter on Science Outcomes. This study was made under the overall supervision of Principal P.L. Shrimali, 1960.

(*f*) This work was later on extended to the first eleven years of school in the area of General Science Education under the guidance of Principal P.L. Shrimali.

Then the whole comprehensive document was approved in a small select gathering of science teachers of Rajasthan at the State Level Seminar held in early 1961 at Udaipur.

(*g*) Developing a Desirable Programme in General Science for the Grades VI, VII & VIII based upon the Analysis of Some Problems and a Critical Evaluation of the same in terms of desirable criteria of the total programme as judged by some teachers—a project report submitted to the Extension Service Department, Teachers Training College, Udaipur, Rajasthan, 1961.

(*h*) Science Education in American Schools, N.S.S.E., Forty-Sixth Year Book, Part I, University of Chicago, 1947.

(*i*) Heiss, O'Bourn & Hoffman, Modern Science Teaching, 1951.

(*j*) Hailsham, Scientific Education in a Scientific Age, Policy for School Science, O.E.E.C., September, 1961.

(*k*) Irvine, Marson, Problems in the National Teaching of Science, British Science Guild, 1931 (The Alexander Pedler Lecture, 1931).

(*l*) Bloom, Benjamin, Educational Objectives and Curriculum Development, Human Learning in the school, edited by De Cecco John P. Holt, Rinehart and Winston. Inc., New York, etc.

(*m*) Dressel, P. L., Nelson, C.H., Questions and Problems in Science published by Co-operative Test Division, Educational Testing Service, Princeton, New Jersey, etc., Copyright 1956.

(*n*) Bloom, Benjamin, Allison, and Deiderich, Paul 'Examining'—In the ideas and practice of general education, Chicago, University of Chicago Press, 1950.

(*o*) Campbel Norman, What is Science ? Dover Publications, 1952.

(*p*) Thurber W.A. and Collette A.T. ; Teaching Science in Today's Secondary Schools, Prentice Hall of India (Private) Ltd.; New Delhi, 1964.

(*q*) Woodburn J.H. and O'bourn E.S. ; Teaching the Pursuit of Science, The MacMillan Company, New York, Collier-Mac-Millan Limited London, 1965.

CHAPTER III

THINKING AND PROBLEM SOLVING

15. (*a*) Humphrey George, Directed Thinking, Dodd, Mead & Company, New York, 1948, p. 1.

(*b*) Rapport David, "Organization and Pathology of Thought, Selected Sources, Columbia University Press, New York.

(*c*) Russel, D.H., Children's Thinking, Ginn & Co., Boston, and London. etc.

(*d*) Peel, E.A., The Pupil's Thinking, Old Bourne London, 1960.

(*e*) Bartlett, Frederic, Thinking, An Experimental Study, Ruskin House, George Allen and Unwin Ltd., Museum Street, London, 1958.

(*f*) Peter Dean, Problem Solving Techniques in Teaching Secondary School Physics—a paper presented at the 32nd annual meeting of the National Association for Research in Science Teaching, Science Education, December, 1961.

18. (*a*) Duncker Karl, On Problem Solving, Psychological Monograph, Vol. 58, No. 5, 1945. It is translated by L.S. Lees.

(*b*) Butt, A.S., The Differentiation of Reasoning Abilities at Adolescene, Ph.D. thesis, 1957, Institute of Education, London.

19. Barbell Inhelder Benjamin, On Problem Solving in the Handbook of Research Methods In Child Development edited by Paul Henry Mussen, John Wiley and Sons Inc. 1960, pp. 421—455.

20. Krech David & Crutchfield R.S., Elements of Psychology (Chapter Creative Problem Solving), University of California, Alfred A. Knoff, New York, 1961.

21. Van De Geer, J.P., A Psychological Study of Problem Solving, Haarlem, Vitgevrej De Toors, 1957.

22. Hindam, Y.H., Problem Solving in Mathematics, Ph. D. Thesis, Department of Education, Birmingham University, Birmingham.

23. Hunt, J. McV., Intelligence and Experience, The Ronald Press Company, 1961.

24. Brownell, W.A., Problem Solving. Forty-first Year Book, Part II, N.S.S.E. distributed by the University of Chicago Press, Chicago 37 Illinois 1942.

25. Gray, J. Stanley, on Problem Solving, pp. 374-396 in Educational Psychology, edited by C.K. Skinner, 3rd edition, Staples Press Ltd., London, 1951, reprinted in 1956.

26. Lester, C. Mills and Peter M. Dean, Problem Solving Methods In Science Teaching, Manpower Project Monographs, Bureau of Publications, Teachers College, Columbia University, 1959.

27. Bingham Alma, Improving Children's Facility in Problem Solving, Bureau of Publications, Teachers College, Columbia University, N.Y., No. 16, 1958.

28. Vaidya, N., A Study of Problem Solving in Science Among Certain Groups of Adolescent Pupils, M.A. thesis Institute of Education, London, 1964.

29. Koffka, K., Principles of Gestalt Psychology, Kegan Paul, French, Trubner and Co. Ltd., New York, Hart Court, Brace and Co., 1936.

30. Sayal and Vaidya, A Study of Problem Solving In Arithmetic Among Certain Groups of Adolescent Pupils, The Rajasthan Board Journal of Education, Ajmer, April, 1966.

CHAPTER IV

SURVEY OF HUMAN PROBLEM SOLVING

31. George Humphrey, Fifty Years Experiment on Thinking in Readings In Psychology edited by Cohen John, George Allen and Unwin Ltd., 1964.

32. Taylor, D.W., and Mcnemar O.W., Chapter Problem Solving and Thinking quoted from Annual Review of Psychology, Vol. 6, 1955, pp. 455 482.

33. John D.M., A Modern Account of Problem Solving Psychological Bulletin, Vol. 41., No. 4, April 1944.

34. Vinacke, W.E., The Psychology of Thinking, Chapter Problem Solving, McGraw Hill Book Co., Inc. New York, 1952.

35. Duncan Carl P., Recent Research on Human Problem Solving in the Human Learning in The School, Readings In Educational Psychology edited by Dececco John P., Holt, Rinehart and Winston Inc. New York, etc. November, 1963.

36. Wheeler D., Studies In The Development of Reasoning In School Children, British Journal of Statistical Psychology, Vol. XI, Part II, 1958, pp. 137-159.

37. Piaget, Jean and Inhelder Barbel, The Growth of Logical Thinking from Childhood to Adolescence, translated by Anne Parsons and Stanley Milgram, Basic Books Inc. 1961.

38. Peel, E.A., The Pupil's Thinking, Old Bourne, London, 1960, pp. 182-83.

39. Ennis R.H., A Concept of Critical Thinking. Harvard Education Review, Vol. 32, Winter 1962.

40. Watson, F.G., Research On Science Teaching in the Handbook of Research on Teaching Methods, American Educational Research Association, Rand M Gnally and Co., Chicago, 1963.

41. Travers, M.W., Essentials of Learning, The Macmillan Company, 1963.

42. Pauli, W., Confusion and Problem Solving, Clearing House 35, 77-82, 1960.

43. (*a*) Matlzman, Thinking : from a behaviouristic point of view, Psychological Review, 1955, 62, 275-286.

(*b*) See also Human Learning in The School Readings in Educational Psychology, Dececco John P. Holt Rinehart & Winston, Inc. New York, London & etc. 1963.

44. Trends in Education, a newly started journal of the Department of Science Education, London, April 1966.

45. Koffka K.. Principles of Gestalt Psychology Kegan Paul, Trench, Trubner & Co. Ltd., London, etc. 1936.

46. Duncker Karl, On Problem Solving, Psychological Monograph, Vol. 58, No. 5, 1945 published by A.P.A.

47. Wertheimer M., Productive Thinking, New York, Harper, 1945.

48. Van De Geer J.P., A Psychological Study of Problem Solving, Haarlem : Vitgeverij De Toors, 1957.

49. David Krech and Crutchfield Richards, Elements of Psychology, Alfred A. Knopf, New York, 1961.

50. Katona G., Organising and Memorizing, Studies in the psychology of learning and teaching, N.Y., Columbia 1940.

51. Szekely L., Acta Psychology, Vol. 7, 1950, Chapters Knowledge and Thinking and Productive Processes in learning and thinking, pp. 338-407 and 1-24. Mellan Publishing Company, Amsterdam.

52. Sleisnick I.L., The Effectiveness of a Unified Science In the High School Curriculum, Ph. D. thesis, The Ohio State University, U.S.A. 1962.

53. Flavell J.H., The Developmental Psychology of Piaget, D. Van Nostrand Company Inc. 1963.

54. Piaget Jean., Logic and Psychology, Manchester University Press, 1956.

55. Inhelder Barbel, Some Aspects of Piaget's Genetic Approach to Cognition, Readings in Psychology edited by Cohen John, Ibid.

56. Jonckheere, A.R., An Exposition of the thought of Jean Piaget, a series of lectures delivered in March 1961, London County Council, Education Officers' Department.

57. Lunzer E.A., Recent Studies in Britain based on the work of Jean Piaget National Foundation Education Research, 1960.

58. Hyde D.M., An Investigation of Piaget's Theories of the Development of the Concept of Number. Ph. D. thesis, University of London, 1959.

59. Children's Reasoning—a repetition of some of Piaget and Inhelder's experiments by members of the A.T.M., in Mathematics Teaching No. 21, Winter 1962, reported by Dr. R.M. Beard.

60. Berlyne, D.E., Recent Development in Piaget's Work, The British Journal of Educational Psychology, Vol. 27, Part 1, February 1957.

61. Lovell K., The Growth of Basic Mathematical and Scientific Concepts in Children, University of London Press, Ltd., 1961.

62. Nathan Issac, The Wider Significance of Piaget's Work and Piaget and Progressive Education published by National Froebel Foundation, London.

63. Churchill E.M., Piaget's Findings and The Teacher, National Froebel Foundation, London, 1960 and 1961.

64. Donaldson M., Work of Jean Piaget and applying his findings to teachings in Scottish Education Journal of December 4, 1959, and December 12, 1959.

65. Piaget, The Genetic Approach to the Psychology of Thought, Journal of Educational Psychology, December, 1965.

66. Vygotsky L.S., Thought and Language edited and translated by Haufmann, Eugenia and Vakar Gertrude, The M.I.T. and John Wiley and Sons, Inc. N.Y. and London.

67. Sleisnick I., The Effectiveness of a United Science in the High School Curriculum, Ph. D. thesis, The Ohio State University, U.S.A. 1962.

68. (*a*) Dienes Z.P., Concept Formation and Personality, Leicester University Press, 1959.

(*b*) Dienes Z.P., The Growth of Mathematical Concept in Children through Experiences, Education Research January 2, 1959.

(*c*) Dienes Z.P., Building Up Mathematics Hutchinson London, 1960.

(*d*) Dienes Z.P., The Power of Mathematics, Hutchison London, 1963.

(*e*) Biggs J.B., Anxiety, Motivation and Primary School Mathematics, N.F.E.R. London, 1962.

69. Journal of Research in Science Teaching, Vol. 2, Issue 3 1964. It contains selected papers from a report of the Conference on Cognitive studies curriculum development 1964 mostly based on Piaget's work.

70. Abou Hatab, The Definition and Measurement by verbal methods of the ability to think critically, M.A. thesis, Institute of Education, 1964.

71. Butt, A.S., The Differentiation of reasoning abilities at adolescence, Ph. D. thesis, Institute of Education, 1957.

72. Peel, E.A., Psychology and the Teaching of Science, British Journal of Educational Psychology, November, 1965.

73. Vernon, P.E., The Psychology of Intelligence and G, in the Readings in Psychology edited by Cohen John, Ibid.

74. Mackay, D.M., Information Theory in The Study of Man in the Readings in Psychology edited by Cohen John., Ibid.

SECTION B

PROBLEM SOLVING (Concept formation)

75. Hull, C.L., Smoke, Haufmann and Kassanin quoted from the abridged account given in the Selected Readings on

the Learning Process by Theodore L., Harris, and Wilson E. Schwahn, New York, Oxford University Press, 1961.

76. Bruner, J.S., Goodnow and Austin : A Study of Thinking New York, Science Editions Inc. 1962.

77. Beard, R.M., An Investigation on Concept Formation Among Infant School Children, Ph. D. thesis, Institute of Education, London, 1957.

PROBLEM SOLVING

78. Buswell G.T., Patterns of Thinking in Solving Problems, University of California Press, Berkeley, 1956.

79. Benjamin Burrack, Methodological Aspects of Problem Solving, Progressive Education, Vol. 30, 1953 pp. 134-38.

80. Heidbreder E., Problem Solving in Children and Adults, Journal of Genetic Psychology, Vol. 35, (1928).

81. Mumford S.C., Factors involved in problem solving with special reference to the problem of insight, Ph.D. thesis, London, 1937.

82. Durkin, H.E., Trial and Error, Gradual Analysis and Sudden Reorganisation, an experimental study of problem solving, Arch. Psychology, N.Y., Vol. 30, 1937.

83. Bloom and Broader, Problem Solving Processes of College Students, University of Chicago Press, 1950.

84. Maier Norman, R.F., Reasoning in Humans, Journal of Comparative Psychology, 1930, 10, 115-43.

TEACHING OF SCIENCE

85. Journal of Research in Science Teaching, Vol. 2, Issue 2, 1963.

86. Oakes, M E., Children's Explanation of National Phenomena, Teachers and College Contribution to Education No. 926, 1947.

87. Deutsche J.M., The Development of Children's Concepts of Causal Relations in Child Behaviour and Development. Edited by Barker R.G. and etc. McGraw Hill Book Company Inc., New York, 1943, p.p. 129-145.

88. Banks S.H., How Pupils in a secondary modern school induce scientific principles from science experiments, unpublished dissertation, Birmingham University, 1958.

89. Navarra J.G., The Development of Scientific Concept in a Young Child, Bureau of Publication, Teachers' College.

90. McNeil J.D., and Keisler E.R., Teaching Scientific Theory to First Grade Pupils by Auto Instruction Device, The Harvard Education Review, Vol. 31, 1961, pp. 72-83.

91. Lahti M., The Inductive Deductive Method and the Physical Science Laboratory, Journal of Experimental Education, 1956, 149-63.

92. Kruglak, H.,
    (*a*) Some behaviour objectives for laboratory instruction, American Journal of Physics, 1951.
    (*b*) Experimental Outcomes of Laboratory Instruction in Elementary College Physics, American Journal of Physics, 1952.
    (*c*) Achievement of Physics Students with and without laboratory work, American Journal of Physics, 1953.
    (*d*) The Measurement of Laboratory Achievement, American Journal of Physics, 1954.
    (*e*) Evaluating laboratory instruction by use of objective type tests, American Journal of Physics, 1958.

93. Muthulingam, An Investigation of Certain Factors in the physical science course of secondary schools in relation to aspects of the achievement, attitudes and interests of fifth year pupils, M.A. Education thesis, Institute of Education, London, 1963.

94. Neal, L.A., D. Ed. thesis reported in Science Education, October 1961, pp. 313-320.

95. Whellock R.B., An inquiry into how far Scientific Method is gained from Scientific Education. M.A. thesis, Institute of Education, London, 1953.

96. Kyle, T., An Investigation of the thought processes of a group of 14 year olds during the solving of a scientific problem, B. Ed. thesis, Glasgow, 1950.

97. Fleshner E.A. and Natadze R.G., Contributed a paper each on Psychology of the Mastery and Application By School Children of Some Concepts in Physics and The Mastery of Scientific Concepts in School in "Educational Psychology in the U.S.S.R." edited by Brian and John Simson, Routledge and Kegan Paul, London, 1963.

98. Mealings R.J., Some Aspects of Problem Solving in Science, M.A. thesis, University of Birmingham, October, 1961.

99. Stendler Celia B., Cognitive Development in Children and readings for high school physics, The American Journal of Physics, December, 1961.

100. (*a*) Quoted from Problem Solving Methods in Science Teaching. A Science Manpower Project Monograph, Bureau of Publications, Teachers College Columbia University 1960.

 (*b*) Quoted from Current Curriculum Studies in Academic Subjects, a report prepared for the project on Instruction by D.M. Fraser, National Education Association, 1962.

 (*c*) The Times Education Supplement, January 10, 1964.

101. (*a*) Harvey G.M., An Investigation into the relation between attitude towards mathematics and various aspects of personality. M.A. thesis Institute of Education, London, 1957.

 (*b*) Bhattacharya Srinibas, The Assessment of persistence and confidence with special reference to secondary school children, M.A. thesis, Institute of Education, London, 1955.

 (*c*) Ab Del Rahman S.M.A., The characteristics of leaders and friends : An experimental study, M.A. thesis, Institute of Education, London, 1961.

102. (*a*) Remmers, H.H., Introduction to opinion and Attitude Measurement, Harper and Brothers, Publishers, New York, 1954.

 (*b*) Guttman, Louis, "A Basis for Scaling Qualitative Data, American Sociological Review 1944, 9 : 139-150.

103. Teachers World, February 28, 1964.

104. (*a*) (*i*) Vaidya N., A Rethinking in our Science Education, The Rajasthan Board Journal of Education, July, 1965.

(*ii*) Vaidya N., Problem Solving in Science, The Alumnus Regional College of Education, Ajmer, March, 1965.

(*iii*) Vaidya N., A highly condensed account of three lectures given by the author at a seminar organized by the Extension Services Department, College of Education Kurukshetra University, Kurukshetra (March 1966).

(*iv*) Kataria M.S. and Vaidya N., External Stimuli and Mental Growth, The Alumnus Regional College of Ajmer, August, 1966.

(*v*) Vijaya Luxmi and Vaidya N., The Education of Backward Children, The Progress of Education in India, May-June, 1966.

(*vi*) Vaidya N., Building Human Welfare, a paper read at the symposium on the Recent Developments in Science organized by the Science Society Teacher's Training College, Vidya Bhavan, Udaipur (Rajasthan) and the report published by the Extension Services Department of the College in 1961.

(*vii*) Vaidya N., Sood J.K., Planning for Science Teaching, Regional College of Eucation, Ajmer (Raj.), 1968.

(*b*) From the academic material distributed by the author when she conducted a workshop on Test Construction at the Institute of Education, Delhi, India in March, 1959.

Additional References

1. Beauchamp George ; A. Curriculum Theory, The Kagg Press, Wilmette, Illinois, 1961.
2. Rethinking in Science Education, N.S.S.E., 59th Yearbook, University of Chicago.
3. Cohen and Nagel, An Introduction to Logic and Scientific Method, Routledge and Kegan Paul Ltd., London, 1961.
4. Donaldson Margaret, A Study of Children's Thinking, Tavistock Publications, 1963.
5. Green T.L., The Teaching of Biology in Tropical School, UNESCO, London Oxford University Press, 1965.
6. Jerslid A.T., Child Psychology, Chapter Reasoning and Concept Formation, Staples Press London, 1960.
7. Maier N.P.F., Problem Solving Discussions and Conferences McGraw Hil Book Company, Inc. 1963.
8. Thorndike, R.L., How Children learn the principles and techniques of problem solving in learning and instruction, 44th Yearbook of the N.S.S.E., 1950.
9. Peel E.Q., The Psychological Basis of Education, Oliver and Boyd, Edinburgh 1958.
10. Stiles L.J., Reflective Thinking, the Method of Education, Dodd, Mead and Company, New York, etc. 1963.
11. Thorndike, R.L., How children learn the principles and techniques of problem solving in learning and instruction, 44th Yearbook of the N.S.S.E.
12. Wallach M.A., Research on Children's Thinking in Child Development, N.S.S.E. (1953), pp. 236-371.
13. William J.D., Teaching Problem Solving, The Kagg Press, Research, N.F.E.R., 1960.

S.C.E.R.T., West
Library